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To be admitted to the Institute the applicant must have attained the age of seventeen years, and must pass examinations in arithmetic, algebra,[1] plane geometry,[1] history of the United States (or ancient history), English and French (or German). A division of these examinations between two successive years is allowed. In general it may be said that a faithful student who has passed creditably through a good high school, having one year's study of French (or German), ought to pass the Institute examinations without much difficulty.

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[1] In 1894 and thereafter advanced algebra and solid geometry will be alternative requirements.

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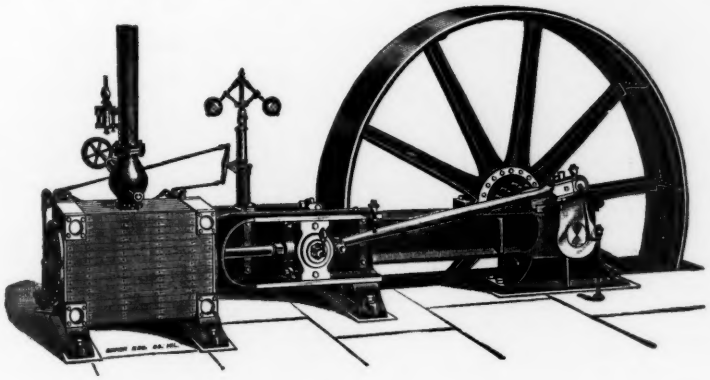

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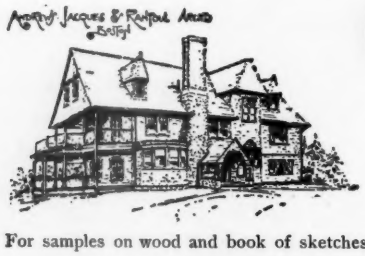

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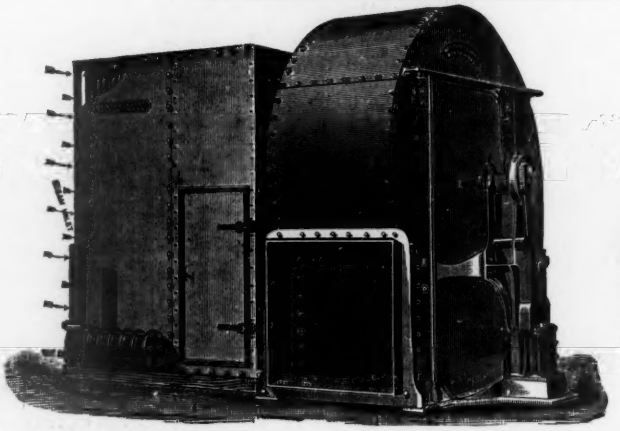

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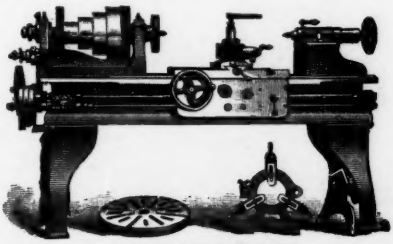

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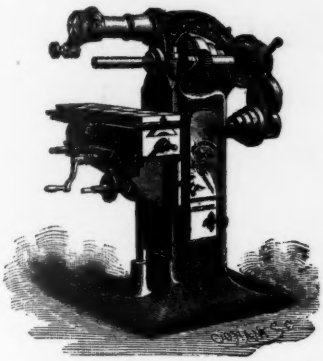

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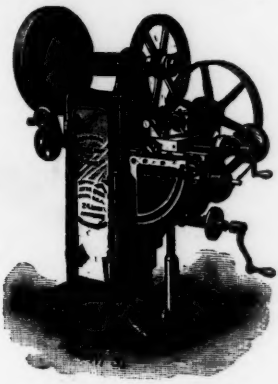

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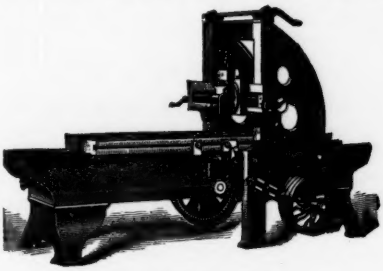

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TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

VOL. VI. APRIL, 1893. NO. 1.

PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-FIRST YEAR, 1892–93.

THURSDAY, January 12, 1893.

THE 440th meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. Prof. G. R. Tucker and Mr. Frederick P. Royce, both of Boston, were duly elected Associate Members of the Society. The Executive Committee reported that they had filled the vacancy in their number caused by the regretted death of Mr. Charles E. Powers by the election of Mr. Henry C. Morse.

The President then introduced Prof. C. H. Peabody, of the Institute, who read a paper on "The Course in Naval Architecture at the Institute of Technology." The paper was illustrated with the lantern, and is published in full in the present number of the *Quarterly*. The meeting then adjourned.

THURSDAY, February 9, 1893.

The 441st meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. The following papers were read by title:

"Study of Bacteria in Drinking Water," by George W. Fuller, S.B.

"Measurement of Steam by the Flow through an Orifice," by E. F. Miller and C. A. Read.

The President then introduced Lieut. W. H. Jaques, of South Bethlehem, who read a paper on the "Manufacture of Heavy Ordnance in the United States," with a special reference to wire construction. It was very fully illustrated with the lantern, and is published in the present number of the *Quarterly*. The thanks of the Society were voted to Lieutenant Jaques for his very able and interesting paper, and the meeting then adjourned.

THURSDAY, February 23, 1893.

The 442d meeting of the SOCIETY OF ARTS was held at the Institute this day at 8 P.M., Col. E. S. Hewins in the chair.

The records of the previous meeting were read and approved. The following paper was read by title:

"Dissociation of Hydrogen Ions from Acid Salts," by A. A. Noyes, Ph.D.

The Chairman then introduced Mr. N. Poulsen, of the Hecla Iron Works, New York City, who read a paper on "Fire-Proof Construction." It was illustrated by drawings, photographs, and models, and is published in full in the present number of the *Quarterly*. At its close Mr. C. J. H. Woodbury spoke briefly on the subject. After a short discussion the Chairman extended the thanks of the Society to Mr. Poulsen, and declared the meeting adjourned.

THURSDAY, March 9, 1893.

The 443d meeting of the SOCIETY OF ARTS was held at the Institute, in the Walker Building, this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. The following papers were read by title:

"On Some Experiments with the Phonograph, Illustrating the Vowel Theory of Helmholtz," by Charles R. Cross.

"The Study of Architecture," by Francis W. Chandler.

The President then introduced Prof. Elihu Thomson, who read a paper on "High Frequency Electric Induction." It was illustrated by numerous experiments, and is published in full in the present number of the *Quarterly*. The President extended the thanks of the Society to Professor Thomson, and declared the meeting adjourned.

THURSDAY, March 23, 1893.

The 444th meeting of the SOCIETY OF ARTS was held at the Institute, in the Walker Building, this day at 8 P.M., President Walker in the chair.

The records of the previous meeting were read and approved. Messrs. Carleton A. Read, of Boston, and J. B. Baker, of Newton, were duly elected Associate Members of the Society.

The President then introduced Mr. W. L. Puffer, of the Institute, who read a paper on the "Action of Compound Dynamos when Run in Parallel." The paper was illustrated by lantern slides, and has been published in the previous number of the *Quarterly*. The meeting then adjourned.

CLEMENT W. ANDREWS, *Secretary.*

THE COURSE IN NAVAL ARCHITECTURE AT THE INSTITUTE OF TECHNOLOGY.

By CECIL H. PEABODY, S.B., Associate Professor of Steam Engineering.

Read January 12, 1893.

Ship-building from the earliest time down to the present day has been an art; only within the present century can there be said to have been a science of ship-building, and even now it is more correct to say that there is a scientific training or preparation given to naval architects, who through practice and experience learn how to apply the ancient art of ship-building.

The art of ship-building is as old as any industry of our country; the glorious success of our wooden clipper-ships and frigates is a remembrance, and has been a regret until our "new navy" has shown that the ability to lead in naval construction may have lain dormant but has never died out. There has, indeed, been no discontinuity, for the shipping built for the coastwise trade and for our great lakes has been large in volume and admirably adapted to its purpose. The designers of these ships have obtained until recently their professional training from experience and individual reading: in this they were like the ship-builders of all the world. To-day the superintendents and designers in the leading English shipyards are men of high scientific attainments; several are graduates of the government school of naval architecture. Already some of the ship-building companies on our seaboard and on the great lakes have placed their work in the hands of men trained either in this same English school or in the French school at Paris; and all the later naval constructors of our navy department have a special training obtained in one or other of the two schools mentioned, or in a school recently established at Glasgow.

Before describing the course in naval architecture now in operation at the Institute of Technology, it will be appropriate to give a brief

account of the two government schools in order that a comparison may be made with them.

The first school in point of time was established by the French at Paris in 1765. It has at various times been moved to Brest, to Lorient, to Cherbourg, and is to-day at Paris. As a matter of courtesy, private students from France and from foreign countries are admitted free. The government students come from the noted Polytechnic School for educating officials for government service, both civil and military. Students are admitted to the Polytechnic School by a competitive examination, held at various cities throughout the country and open to all young men between the ages of sixteen and twenty. The applicants for these examinations are numerous and the competition is close, so that the students at the school are a select class. The examination includes arithmetic, geometry, algebra, trigonometry, analytical geometry, descriptive geometry, physics, chemistry, drawing, French, and German.

The course at the Polytechnic School is two years long, and gives instruction in geometry, calculus, mechanics, stereotomy, astronomy, physics, chemistry, topography, mechanical and free-hand drawing, literature, history, and German. A very careful system of ranking is carried through the whole course; and on graduation the students, to the number of about one hundred and twenty-five, are allowed to choose, in order of their rank, appointments in the various branches of government employment open to them. The appointments in naval construction, to the number of four each year, are taken by men near the head of the list. In a manner these two years may be compared with the first two years in our engineering courses at the Institute of Technology.

The course in the School of Naval Architecture is, also, two years long, and provides instruction in naval construction, strength of materials, naval architecture, the steam engine, thermodynamics, naval ordnance, accounts, English, mechanical and free-hand drawing, and ship and engine drawing. During the course illustrative instruction is given by visits to arsenals, workshops, and vessels. In the summer intervening between the two years students are required to use the time from July 1 to September 20 in the dockyards and engine works, where facilities are given them for becoming familiar with practical work.

The education of naval architects in England has received atten-

tion in an irregular manner for nearly a century; it is only in comparatively recent years that a fixed policy has been followed. In 1811 a school in naval architecture was opened in Portsmouth, and again one was opened in 1853; neither was maintained long, and their influence was limited. In 1864 a school was opened at South Kensington, which in 1873 was united with the Royal Naval College at Greenwich. The men trained in the school at South Kensington now hold important positions either in government employment or in private yards.

The Royal Naval College is charged with all the higher scientific instruction for the British Navy, with the exception of gunnery and the use of torpedoes. The most thorough instruction is given to a small group of students, known as "students in naval architecture and engineering," extending through three years.

The English naval engineers are selected by open examination at fourteen to sixteen years of age, then pass a six years' apprenticeship in the dockyards and finish with a course of one year at the Naval College. Each year two engineers are selected to take two additional years' training at the college. In a similar manner dockyard apprentices, at the age of fourteen or fifteen, are taken into the dockyards for a seven years' apprenticeship. Every year three apprentices are selected by competitive examination for study at the Naval College. The examination for admission to the dockyards is much the same for both classes of apprentices, and includes arithmetic, geography, algebra, geometry, reading, and writing. Together with practical instruction the apprentices are taught in the dockyard schools algebra, descriptive geometry, analytical geometry, calculus, and mechanics.

The first year at the Naval College for both engineers and naval architects is much the same as for a rather large class of naval officers and naval engineers. Then a two years' course is given to the small and select class of engineers and naval architects, which is the same for both in theoretical work, but differs in professional work. Private students are admitted to the whole three years' course, and several of our later naval constructors have had the advantages offered by this school.

The theoretical work includes mathematics, physics, chemistry, and mechanics, and is of the highest character, including training in well-equipped laboratories. The special professional work in naval architecture is of particular interest, and will be given at length from an

account by Mr. W. H. White, then an instructor at the school and now the chief constructor for the English Navy. Though the account was given some years ago, it is substantially correct now. The course at that time was so complete that improvement would appear to be possible only in the perfection of methods and details.

In the first year one or two afternoons a week are given to ship calculations as follows:

1. Proofs and applications of rules for finding the areas and position of the center of gravity of plane curves.

2. Proofs and applications of the rules for finding displacement of ships and center of buoyancy.

3. Construction and use of curves of displacement, tons per inch of immersion, and area of midship section.

4. Proofs and applications of rules for calculation of the metacenters for transverse and longitudinal inclinations.

5. Construction and use of metacentric diagrams.

6. Explanations and applications of rules for tonnage measurements.

7. Graphic representations of the longitudinal distribution of the weight and buoyancy in ships floating in still water, together with the construction of the curves of loads, shearing forces, and bending moments.

In the earlier part of the second year the students are taught how to perform the following more difficult operations:

1. Calculations for statical stability and construction of curves of stability.

2. Calculations for dynamical stability by Moseley's formula.

3. Calculations for and construction of the loci of the center of buoyancy, metacenter, and center of flotation of ships for all tranverse inclinations under certain assumed conditions.

When this work is finished the students are ready for a ship design, which occupies two or three afternoons a week for the remainder of the second year and for the whole of the third year, and on this design the students work in twos or threes. The character and extent of the work is shown by the following outline:

1. Preliminary estimate of dimensions and displacement.

2. Preparation of sheer-plan, midship section, outline specification for scantlings, plans of decks, etc.

3. Calculations of displacement, and positions of the center of buoyancy and metacenter.

4. Detailed calculations for weight of hull, armored and fitted, together with the position of the center of gravity.

5. Detailed estimate of weights of equipment and position of their center of gravity.

6. Combinations of 4 and 5 to determine the weight and the position of the center of gravity of the completed ship; determination and application of corrections to the preliminary estimates, after which the design is made determinate and requires only the working out of details.

7. Preparation of outline profile and plans of decks and hold.

8. Preparation of sail draught, etc.

9. Calculations for and construction of curves of displacement, tons per inch of immersion, and immersed midship section; also for metacentric diagram.

10. Calculations for statical and dynamical stability.

11. Calculations for speed under steam.

12. Calculations for longitudinal bending moments in still water and among waves, etc.

13. Calculation of equivalent girder and estimate of longitudinal strains on the structure.

During the third year the students receive instruction by lectures and otherwise on the following subjects:

I. STABILITY OF SHIPS.

1. General theorems of Dupin, etc.

2. Metacentric methods of estimating initial stability, etc.

3. Applications of the metacentric methods, including: Inclining experiments to determine the vertical position of the center of gravity of a ship; variations of stability due to the addition or removal of weights; changes of trim produced by moving weights or the adding or removing of weights; efficiency of various methods of water-tight

subdivision in preserving the stability of ships when compartments are bilged; stability of ships aground; estimates of power to carry sail.

4. Stability at finite angles of inclination, with details of the various methods of calculation that have been proposed by Atwood, Read, and Barnes. Calculations for and construction of curves of stability. Examples of the forms of such curves for typical ships. Influence of beam, free board, draught, and vertical position of the center of gravity upon the forms of curves of stability.

II. DYNAMICAL STABILITY.

Moseley's formula and other expressions for dynamical stability; estimates by direct calculation or from curves of stability of the safety of ships when acted upon by gusts or squalls of wind; reserve of dynamical stability.

III. OSCILLATIONS OF SHIPS.

1. Unresisted rolling in still water.
2. Rolling in still water, with effect of resistance included.
3. Still water rolling experiments, etc.
4. Dipping oscillations in still water.
5. Rolling among waves.
6. Principal deductions from the theory of rolling.
7. Pitching oscillations.
8. Heaving and yawing.

With the paper by Mr. White are given diagrams showing work done by students, which differ only in detail from some that I shall show later in the statement of our own course.

Before giving a detailed account of our own course I ought to mention the very excellent course of naval architecture given at the University of Glasgow.

THE COURSE AT THE INSTITUTE OF TECHNOLOGY.

A brief history of the progress in instruction in marine engineering and naval architecture at the Institute of Technology will show that the growth has been natural, and that our course is well rooted and grounded. In 1886 options in mill, locomotive, and marine engineer-

ing were offered to the fourth-year students in mechanical engineering. To these options were assigned three lectures a week for one third of the first term and all of the second term. Though the time has remained the same, the options have been extended and strengthened by preparation and arrangement of material and by the improvement that has steadily gone on in the regular work of the third year. Inasmuch as it appeared advisable to give the students in marine engineering some idea of the form, construction, and properties of ships, an elementary course of such instruction was given in 1888: this was the first attempt to give regular instruction in this line in this country, for the excellent evening classes in ship-drawing in this city are intended for quite a different class of young men. Year by year the instruction has been improved and enlarged until some regular provision for it outside of the option in marine engineering became imperative. In 1890 the option of naval architecture was established, with two lectures a week for the second term of the fourth year. Last year a further expansion was made by assigning lectures and drawing exercises in the first term, and a substantial amount of work was done by students taking the option. This present year the instruction in naval architecture comprises three lectures a week the first term and two a week the second term, together with six hours of drawing each week for the entire year.[1]

In comparison with other schools we ought perhaps to give some account of the work in the course of mechanical engineering leading up to and accompanying the instruction in marine engineering and naval architecture, including the mathematics, drawing, chemistry, physics, applied mechanics, mechanism, steam engineering, modern languages, literature, history, etc., together with a description of the work and training in our workshops and in the laboratories of chemistry, physics, applied mechanics, hydraulics, and steam engineering; but such a statement would be tedious, and is unnecessary for those who are familiar with the methods and work of our school. The students taking the naval option are required to take the marine engineering option also, so that an account of this should be given. It includes:

1. Description of marine and stationary engines in all their details, including the most modern types.

[1] Since this paper was read, a regular four years' course in naval architecture has been established at the Institute of Technology, following the lines laid down here, but enlarged in scope and improved in details.

2. The usual discussions and calculations of the strength and proportions of marine and stationary engines.

3. Discussion of the probable behavior of steam in the cylinders of a proposed engine, considering different types and arrangements.

4. Discussion of the effect of the reciprocating parts in combination with the preceding work, with the object of determining the greatest stresses on the parts of the engine.

5. Comparison of these results with the results of the usual methods.

6. A discussion of the forms, efficiency, and construction of paddle wheels and propeller screws.

The last four involve a large amount of drawing and calculation by the students. The classroom work in naval architecture takes up the following subjects:

1. A description of the methods of building ships in iron and steel, including transverse and longitudinal framing, the fitting of double bottoms and ballast tanks, the laying out, erection and fairing of the framing, fitting of bulkheads, and the shell and deck plating.

2. Proofs and applications of rules for finding the area, moment, moment of inertia, center of gravity, and radius of gyration of lines, areas and volumes by Simpson's rule, the trapezoidal rule, and by the Amsler-Laffon integrator.

3. General discussion of the properties of floating bodies, with especial application to ships. Taking up the discussion of curves and surfaces of buoyancy and flotation, and of similar curves and surfaces for a layer due to increased displacement; the discussion of the metacenter and metacentric curves and of statical and dynamical stability. Also taking up applications of the metacentric method to inclining experiments for determination of the center of gravity of existing ships, to the determination of the variation of stability and the change of trim due to the addition, removal, or shifting of weights, and to the grounding of a ship, with especial reference to docking and launching. Also a discussion of the effect of carrying fluids in tanks wholly or partially filled, including water ballast tanks and double bottoms; also the effect of the flooding of the various compartments of a ship.

4. Explanation of the methods of finding statical and dynamical

stability of ships proposed by Barnes, Benjamin, Spence, Daymard, and others.

5. Explanation of the methods of finding the weight, center of gravity, moment, and moment of inertia of the hull, equipment, and cargo. Determination of loads, shearing forces, and bending moments acting on the hull of a ship in quiet water and when borne by waves.

6. Explanation of the methods of determining the equivalent girder for the hull of a ship and of determining the stresses produced by the weight of the hull, equipment, and cargo, whether floating in still water or borne by waves.

7. Rolling of ships.

8. The trochoidal theory of oscillating waves; waves of translation, their character and methods of formation.

9. Resistance of ships due to surface friction and to the formation of waves. Experiments on models and comparisons of ships of similar types.

10. Preliminary methods of laying out the design of a ship and procedure for completing the design.

A large part of the work detailed in the first seven heads has been given already, and the remainder is ready for the class. The work under the last head is not yet arranged, but some substantial work will be done. The drawing-room work includes:

1. The laying out and fairing of the lines of a ship. Figure 1 shows a set of lines drawn this year.

2. Calculation of a displacement sheet in the ordinary form.

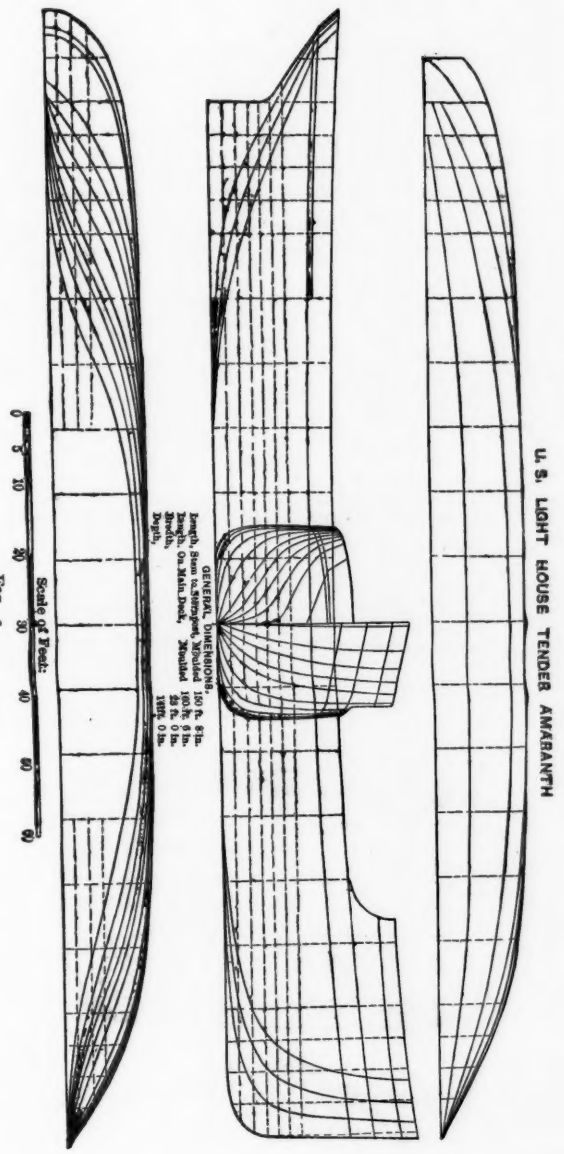
U. S. LIGHT HOUSE TENDER AMARANTH
GENERAL DIMENSIONS.
Length, Straight of Keel, Moulded 150 ft. 6 in.
Length, Straight of Stem, Moulded 160 ft. 6 in.
Length, Out Main Deck, Moulded 25 ft. 0 in.
Breadth, 13 ft. 0 in.
Depth,
0 5 10 20 30 40 60 80
Scale of Feet.

FIG. 1.

3. Drawing of curves of displacement, tons per inch of immersion, center of buoyancy, areas of midship section, areas of water lines, and transverse metacentric heights. Figure 2 shows such lines drawn this year.

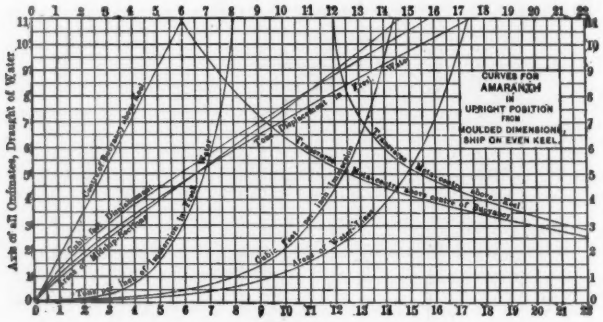

FIG. 2.

4. Calculations of the statical and dynamical stability by the methods of Barnes and by the method in use at the Bureau of Construction and Repair of the Navy Department.

A double body plan used in the calculations by both methods is shown by Figure 3. The inclined water line used in Barnes' method

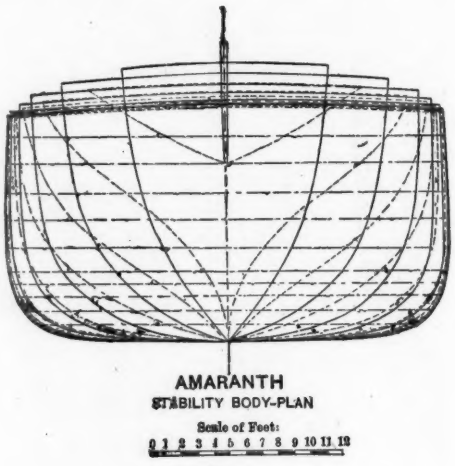

FIG. 3.

is shown by Figure 4. Figure 5 gives the cross curves used in the method of the Bureau of Construction and Repair, and the curves of statical and dynamical stability derived therefrom.

5. Calculations of the weight and center of gravity of the hull, equipment, and cargo; also the calculations for trim. For this work

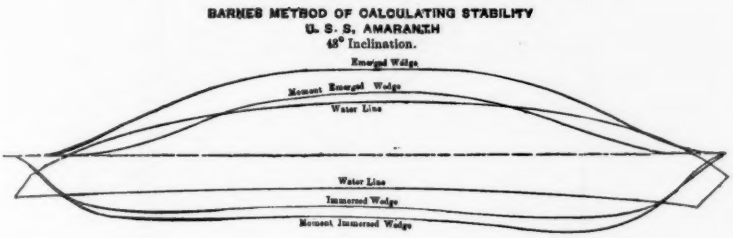

FIG. 4.

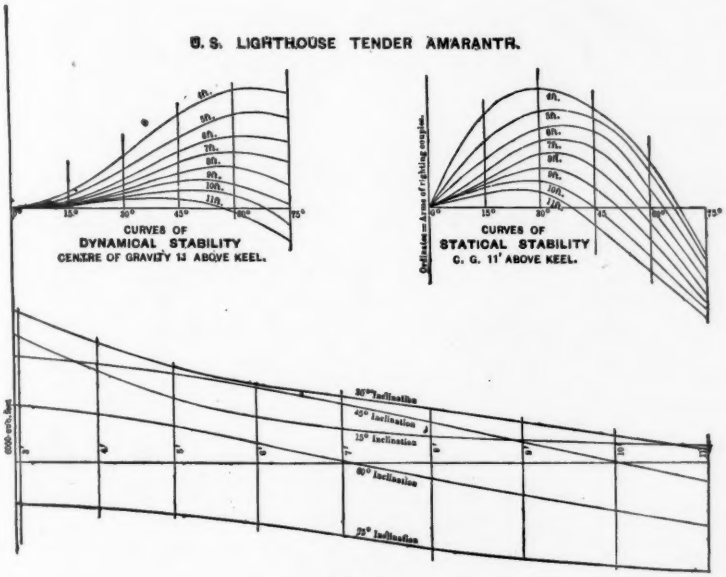

FIG. 5.

the student draws one of the sections of the ship, shown by Figure 6, and is furnished with other necessary data from the specifications of a ship recently built. Each student does enough of the work to

become familiar with the processes, and then the work of all the students is combined to complete the problem.

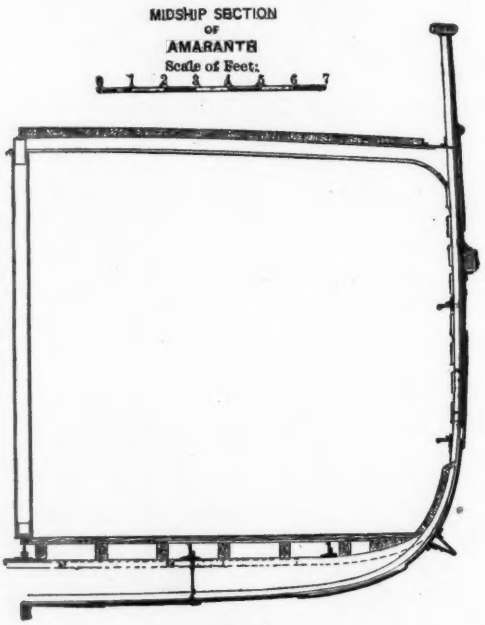

FIG. 6.

6. Calculation and drawing of the curve of buoyancy, weights, loads, shearing forces, and bending moments acting on the hull. The drawing is shown by Figure 7.

7. Drawing of the equivalent girder and calculation of the stresses on the hull.

The material that we have in the department, in addition to recent and standard works, includes drawings of many engines of important ships, both naval and mercantile, together with the lines and specifications of ships. Much of the material has been worked up in such a way that it is directly available for use with the class, and is now in use. Other material is promised to us as soon as ready, and will be worked up in a like manner.

Our course has been developed to conform to the needs and methods of our school, with the aid and advice of graduates of both the French

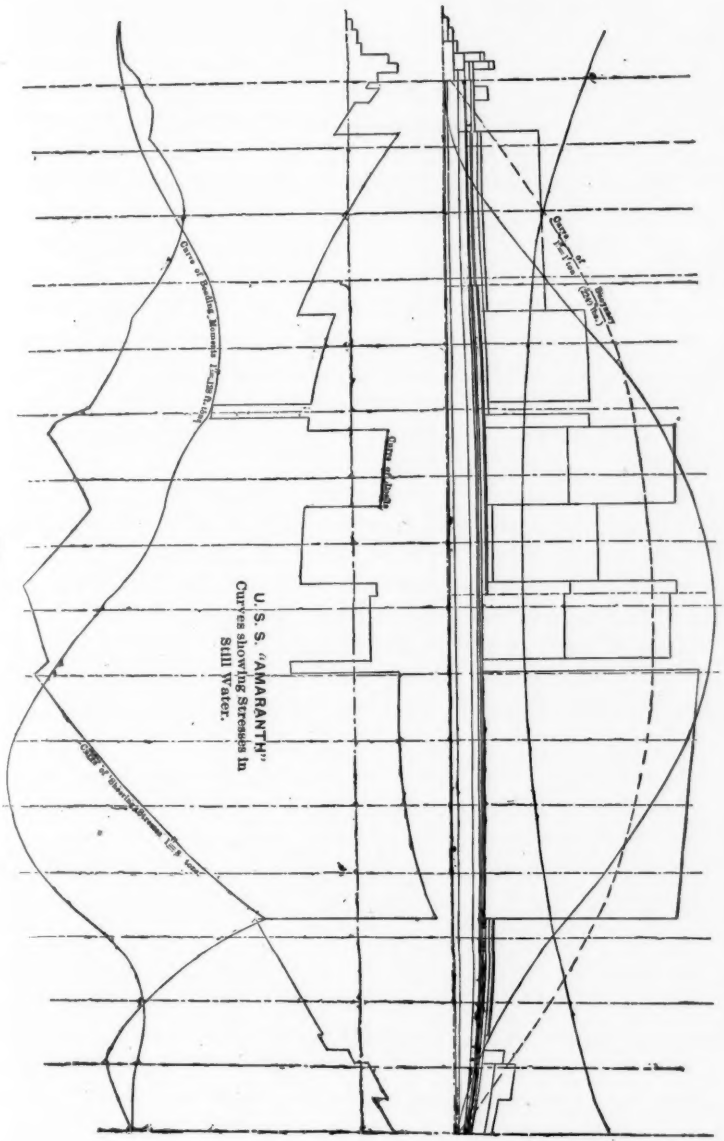

FIG. 7.

and the English schools, but without the intent of copying either. The instruction of our school differs from that of the English school in giving less time to drawing and calculation and in not attempting an elaborate design. In this work, as in all the work of the Institute, the time of the student is economized by careful preparation and arrangement of the work he is required to do, sometimes by lavish use of the time and strength of the instructing force. Each student is required to do enough of the detail work of calculation and drawing to familiarize him with the methods, and no more. In such work a large saving of time is made by a free use of mechanical integrators. In the course of drawing and calculation laid down, the student meets and masters all the problems that arise in the design of a ship, and applies them, as he learns them, to a ship of good design. Much of the work of a complete design of a ship is tedious and wearisome from the repetition of details. We do not believe that our men need or can afford to do much such work now. We aim rather to give a thorough grounding in principles, to teach good methods, and to give enough practice to enable the student to work intelligently. Finally, we believe that our graduates who take naval architecture will be able to begin work immediately in some useful position, even though it be at first a subordinate one; that they will quickly and thoroughly master that part of their profession which depends on experience; and that they will in time be able to take the highest positions the profession offers, in which they will only follow the traditions of our alumni.

MANUFACTURE OF HEAVY ORDNANCE WITH SPECIAL REFERENCE TO WIRE CONSTRUCTION.

By W. H. JAQUES, Ordnance Engineer.

Read February 9, 1893.

As a preparation for a comparison of the methods of employing "wire" with the generally accepted "built up" type, I will hastily review my lecture delivered January 6 before the Franklin Institute, Philadelphia, and illustrate the method of making our present form of heavy ordnance that you may be able to form your own estimates and make your own comparisons with what will follow in relation to "wire" construction. Both subjects are too extensive to have justice done them in a lecture of an hour and a half. I shall attempt, therefore, only a short historical sketch. For convenience in comparing the two methods I shall use the expressions "hooped" and "wire."

[Mr. Jaques then described the operations of manufacture, treatment, and assemblage of the "hooped" guns, giving an account of the material of which they are made and the growth of the mechanical means for its production; experiments with other materials and other types; development and test of nitro-compound powders; effective power of shrinkage; effects and prevention of erosion; methods of closing breech and checking gas; the value of nickel in steel; importance of "monster" guns; mortars, pneumatic and submarine guns; rapid-fire ordnance; effect of modern steel projectiles on steel, nickel-steel, and case-hardened (carbonized) armor; the whole illustrated by one hundred lantern views, a few of which, relating directly to "wire" construction, have been reproduced in this issue.]

Turning to that branch of gun-making, wire-wrapped ordnance, concerning which your Committee has asked me to speak, I find it even more difficult to formulate any *concise* statement that can help you to form an estimate of its value. A large amount of experimentation has been carried on, but few practical results have been obtained.

In England remarkable velocities and ranges have been secured, but these have been equaled by the "hooped" gun; in Russia the guns tested have shown great endurance, but in other countries nothing of importance has been done. In the United States, of the two guns tried one failed, while of the other (cast iron) the Board of Ordnance and Fortification has reported: "The muzzle energy of the gun is so much less than that of the steel gun, and the erosion so much greater, that the Board for Testing Rifled Cannon does not recommend it as suitable for service under present conditions." It must be remembered that the tube of this gun is of cast iron, and that its rejection must not be ascribed alone to its belonging to the class of "wire" guns.

This type of construction, in one form or another, appears to ante-

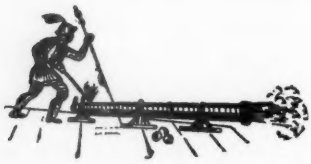

FIG. 1.

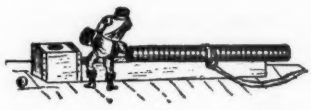

FIG. 2.

date all others. In seeking for the earliest date when ring, hoop, or coiled guns were used, in order to mark the stages of transition, I have not been able to find anything earlier than the statement of Archdeacon Barbour that Edward III, with whom he was contemporary, employed cannon in 1327 in his campaign against the Scots.

Froissart refers to the general employment of cannon in 1340, but does not give until 1390 his first representation of the guns of the period (Figure 1). The next illustration of an iron gun is that of the battery of the "Mary Rose," a war vessel sunk in 1545. The gun, of which Figure 2 is an approximate sketch, is said to have been recovered after an immersion of three hundred years. Both guns are evidently breech-loaders, and each is formed of a tube probably with a longitudinal lap (perhaps welded), additional transverse strength being obtained by shrinking on the narrow rings shown in the sketches. These rings were supposed to be made from iron three inches square, and the earlier descriptions call them "immense rings." These "immense rings" have dwindled to 0.03″ section for wire, and developed

(as the means of producing them have been provided) into jackets, for the 13-inch navy gun, for example, of $38\frac{1}{4}$ inches outside, and $23\frac{3}{4}$ inches inside diameter by $204\frac{1}{2}$ inches in length, weighing eighteen tons. The hoops or rings referred to above were driven over the tube or barrel when hot, the usefulness of shrinkage, although not carried to thousandths of an inch, being then recognized.

Both wire wrapping and wrought-iron coils are doubtless further developments of the barrel-welding of small arms. Greener says: "In the routine of good gunmaking, barrel-welding in importance is inferior only to the *quality of iron*," and that "the best barrels have more joinings than common ones of equal length." This would seem to be true of the modern wire-wrapped gun, since the greatest elastic strength is obtained with the smallest section.

Although with the ultimate object of producing tubes and hoops, the next prominent method of wrapping metal was that employed in the construction of the guns to which the names of Armstrong and Fraser were given. The coiled-iron cylinders of Armstrong, which have received so much adverse criticism, may be taken as a species of wire-gun construction, a type in which the cross-section was excessive. The spiral winding and lateral welding gave slight longitudinal strength; but the material — iron — was not strong enough, and the guns were always unreliable. In referring to the system in 1882, Armstrong argued in favor of these coiled cylinders because the barrels of fowling pieces had long been made on the principle of welding a spiral coil of soft iron in a continuous tube, and he believed that coil cylinders of the continuous fiber of rolled iron would resist the more potent bursting strain, while the lateral welds would provide sufficient longitudinal strength. In practice, however, this proved not to be the case. This method of construction, although retained in Great Britain from 1857 to 1885 (probably the longest period held by any British type), was not adequate, and many guns built in accordance with it came to grief.

To get longitudinal strength in his gun of 1860, Armstrong used an intermediate layer between the outer and inner coils, composed of iron slabs bent into cylindrical form and welded at the edges. The reason for this construction was that the intermediate layer has chiefly to sustain the thrust on the breech, and it is therefore desirable that the fiber of the iron should be in the direction of the length, while elsewhere in the gun it is more advantageously applied in the trans-

verse direction. Armstrong here provided separate means for resisting the longitudinal and transverse strains, but did not separate them as Longridge does in his type. It is a point that might well be considered whether the increased friction resistance of the "shrinkage" form is not of more value than any tendency of separation that this friction might produce. In 1863 the coiled wrought-iron tube was replaced by a steel forging, but the wrought coiled strengthening hoops were retained.

The bars for these coils were all about 3″ x 5″ section, 30′ lengths being end welded and wound upon a mandrel. The coiled cylinders (Figures 4 and 10) thus made were placed upon end, welded, and shaped under a hammer until cylindrical hoops (Figure 7) of the requisite length were formed. These lengths depended somewhat upon the capacity of coiling and welding machinery, but usually had to be made in short lengths because of the unequal welding of a large number of joints.

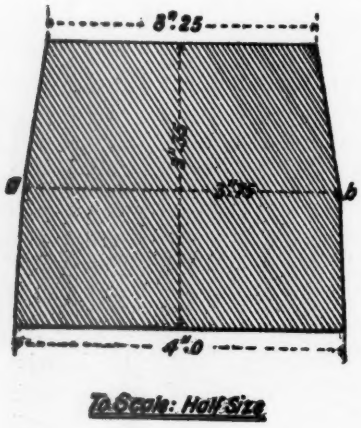

FIG. 3.

FIG. 4.

In 1867 Mr. Frazer, attached to the Woolwich establishment, simplified the Armstrong construction by reducing the number of coils, making them of thicker bars, and welding the trunnion band upon the breech coil; and in 1874 it was probably brought to its highest stage of efficiency when the 12-inch, 38-ton, muzzle-loading rifle composed of steel tube and wrought-iron coils gave a muzzle velocity of 1,410 feet seconds and a muzzle energy of 9,650 feet tons to a 700-pound projectile of 3 calibers length. In this gun the tube coils were welded from 4″ x 7″ section wrought iron, and the strengthening coils from 7″ x 12½″ section.

In Great Britain the change from wrought-iron coil ordnance to

forged steel, when it did come, was rapid. An English authority writes: "In 1882, when a powerful British fleet engaged the forts of Alexandria, there was no heavy gun on board in the construction of which wrought iron had not been largely used; nor were there any heavy breech-loading guns; while to-day (1891), on the contrary, all our modern iron clads are armed with breech-loading guns built entirely of steel."

FIG. 5.

FIG. 6.

The departure in both directions from Armstrong's wrought-iron coil construction resulted in an increase of strength. By way of the "Frazer" modifications the solid steel hoops and jackets were reached, while by way of thinner and smaller coils the wire system was perfected, in both cases steel becoming the accepted metal.

Although Armstrong's name has been welded to the coil construction, Blakely, I believe, had secured a patent for it before Woolwich and Elswick adopted it. The British patent records credit him with the idea.

The failures of the coiled iron guns showed them to be very deficient in longitudinal strength, the splitting of the inner coil and the separation of the coils being of frequent occurrence. Even with the low pressures employed, the wrought-iron coils were stretched beyond their elastic limit, and the barrel, not being adequately supported, gave way.

FIG. 7.

In the United States wrought-iron coils were extensively used for the conversion of Rodman and Dahlgren guns into muzzle-loading rifles. In the fabrication of the coil wrought-iron gun tubes, at the West Point Foundry, for the conversion of 10-inch Rodman smooth bore guns into 8-inch rifles, Lake Champlain pig was puddled and rolled into 23′ bars of 3.25″ to 4.0″ x 3.35″ irregular cross-section (Figure 3); these were scarfed to requisite coiling lengths by butt and lap welding, after which they were heated in long furnaces and coiled (Figure 4) upon a taper mandrel operated by steam. The coils were then welded (Figures 5 and 6) in banded cast-iron tubes called "welding pots;" after which the sections (Figure 7) were end welded to form the tube. In the Armstrong

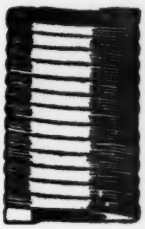

FIG. 10.

wrought-iron coils the cross-sections of the bars employed were 2.2″ to 2.5″ x 3.2″ for the 8-inch (Figure 8) and 3.05″ to 4″ x 5″ for the 12-inch tubes (Figure 9), both of irregular cross-section. The coiling was done by Armstrong and at West Point by similar methods.

For forty years the names of Longridge, Woodbridge, and Shultz, and later Armstrong, have been prominently identified with "wire" gun experiments and development. To many others who have entered the race, reference will be made hereafter. Dr. Woodbridge's claim of priority of the idea seems to be established by the record of a plan for a wire-wound gun presented to the War Department July 30, 1850. Although Blakely's name has not been frequently mentioned, a patent for the use of coils

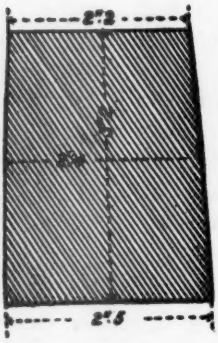

FIG. 8.

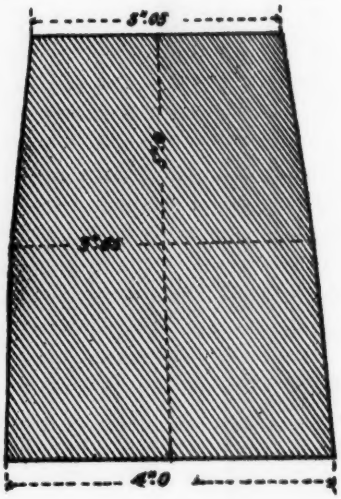

FIG. 9.

of wire for the strengthening of old and new guns was granted him February 27, 1853.

The early objects of wire construction were not only to increase the strength of guns, but to lessen the weight of the parts used in the construction of "heavy ordnance" before the advent of the mechanical means and metallurgical experience that have brought about the successful production of gun steel to so well meet the requisites of high power construction. Steel wire of small section and different forms was employed. The great increase of the elastic strength of steel by wire drawing enabled the requisite tangential cohesion to be

easily secured, but the condition was complicated by an absence of adequate longitudinal or end strength. From a good wire steel of 75,000 pounds tensile and 37,000 elastic, physical qualities of 250,000 tensile and 200,000 elastic limit have been obtained in a square section of .07″, and in No. 22 music gauge steel wire the strength has run as high as 142 tons per square inch. While this high elastic strength is of great value in caring for transverse strains, it has not yet been successfully applied to decrease to any great degree the lack of longitudinal or end strength, which is an inherent defect of most wire-wrapped types. Longitudinal winding has been tried, but it increases the difficulty of manufacture; and the excrescences upon the tube or body of the gun often prevent uniformity in the metal, while the sudden changes of form interrupt the synchronous and elastic movement of the metal and produce rupture.

From the prolific literature on the subject I have selected the opinions of some of the men who have given the question careful thought and who have directed many of the experiments, and I have at least kept the system among its friends.

In respect to the use of steel wire of comparatively small cross section or of steel ribbon, Armstrong claims, although his patent is dated December 28, 1880, to have given it his practical attention as early as 1855, and referred to it at considerable length in a lecture delivered before the British Institute of Civil Engineers January 10, 1882. He spoke of the system as being still in an experimental state, but believed it would attain wide application although there seemed many difficulties of putting the theories so strongly advocated into practice.

Armstrong also stated that in 1856 Mr. Brunel independently conceived the same idea as that presented by Blakely and Longridge, and requested him (Armstrong) to make a gun on the wire-wound principle; but that soon becoming acquainted with the priority of other patents the idea was given up by both Mr. Brunel and himself. In 1878 Armstrong's attention was again directed to the subject, when the patents already referred to having expired he made some preliminary experiments with small cylinders and in 1879 commenced the construction of a 6-inch breech-loading gun, which was completed and tested the following year. With it larger charges were used and higher energies obtained than with similar calibers of other types. As these results were satisfactory, a 26 cm. (10.23 inch) was constructed. It was

29 calibers long and weighed 21 tons (Figure 13). His 6-inch gun depended for longitudinal strength upon the cohesion of the barrel only, but in the latter (10.23 inch) he employed longitudinal layers of wire in the proportion of one longitudinal to four transverse layers. Of this particular construction Armstrong has written: "The longitudinals are secured to the trunnion ring at one end and to a breech ring at the other, and are in themselves calculated as sufficient to resist the end strain on the breech independently of the strength afforded by the tube. The whole is encased in hoops shrunk upon the exterior of the coil, for the treble purpose of protection from injury, of preventing slipping in the event of the failure of an external strand, and of adding to the strength of the gun. With regard to the ribbon form of section, I prefer it to a square section of equal area as being more favorable for bending over a cylinder; but any rectangular form is better than round wire on account of the flat bedding surfaces it affords." This gun when tested gave results unexampled, in relation to its weight, except by its 6-inch predecessor.

FIG. 11.

In 1884 Colonel Maitland referred again publicly to constructions

FIG. 12.

"which involve the employment of wire, which may, perhaps, supersede those consisting entirely of forged steel. They are chiefly experimental, but some have been made and actually issued for service to Chili by the firm of Sir W. G. Armstrong, Mitchell & Company. Competitive designs have been prepared for the War Office by the same great firm and by the Royal Gun Factory for guns of this kind. Figure 11 shows a section of the 18-ton wire gun proposed by Elswick. The Royal Gun Factory design submitted at the same time is shown

in Figure 12. In this latter construction the whole of the metal over the chamber assists in supporting the transverse strain. The longitudinal strength is divided about equally between the tube and the outer hoops, and is ample."

This desire to diminish the weight of ordnance is not limited to any recent period. Several times in the history of gunmaking lightness of construction has been carried to excess with consequent reactions. Colonel Chesnsey and Captain Fave describe a method of construction to secure lightness in which different materials were employed from those now used for wire-wrapped ordnance; and if there had been a patent union in existence in which Gustavus Adolphus could have secured a patent for the principle he might have reaped quite a valuable sum for royalties. These guns were made partly of boiled leather, and were used by Gustavus Adolphus at the battle of Leipsic, in 1631. They consisted of a thin cylinder of beaten copper screwed into a brass breech, the chamber of which was strengthened by four iron bands. The tube was covered with layers of mastic, over the entire length of which cords were firmly wound, and equalized by a layer of plaster. A coating of leather, boiled and varnished, completed the piece.

FIG. 13.

In this description we find nearly all the elements of a principle of wire gun construction except the separation of the provisions for longitudinal and transverse strength. The gun was chambered, the chamber was jacketed, coils of rope provided tangential strength, while the leather covering protected the coils from injury.

In various papers read before the British scientific institutions the advantages of "wire" construction have been presented and frequently discussed by Armstrong, Maitland, Longridge, Bramwell, Jones, and Hope. Many other authorities have spoken favorably of wire-wrapped ordnance, but since the appointment of Dr. William Anderson as Director General of Ordnance Factories the manufacture of wire-wound guns has rapidly progressed at Woolwich. Dr. Anderson has been interested in wire-gun construction for many years, and has always advocated the Longridge system.

The condition of the question in England in 1891 was well described in the issue of the London *Engineer* of October 2, 1891: "The

points which in our judgment deserve attention specially in connection with the gun factories at present are the manufacture of wire guns and the behavior of steel under the action of the burning of the powder charge. Mr. Longridge may at all events at length have the gratification of seeing wire guns likely to come in on a sweeping scale. For several years past their superiority has been fully recognized."

In 1892 Dr. Anderson himself expressed the opinion that a large gun made of steel wire must necessarily be more reliable than a gun built up of forgings. He gave as his reason for this "that we know

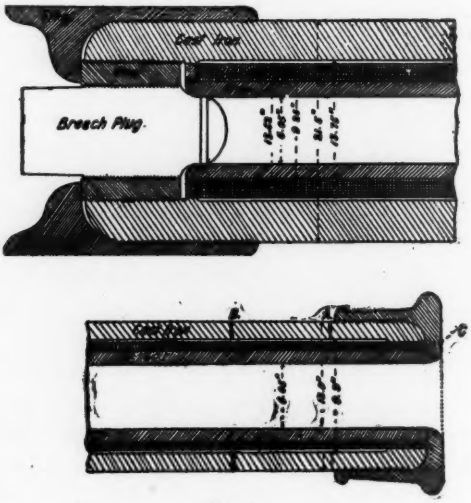

FIG. 14.

nothing of the internal molecular conditions of large masses of steel, whereas we know the exact state of structure built up of separate wires. Then, also, the tensile strength of steel wire is more than twice as great as that of a mass of steel." Dr. Anderson stated that they are conducting experiments with wire guns at Woolwich Arsenal, and that in all probability he will be able to give the results shortly.

Mr. Longridge has been the most persistent advocate of the application of wire to the construction of ordnance, and among the several forms that have emanated from the many inventors his last is undoubtedly the best type. His suggestions for the complete separation of the longitudinal and transverse strength are valuable, and the use

of the long jacket not only provides ample longitudinal strength, but serves to protect the wire from injury and displacement.

March 18, 1887, the British Parliament asked some questions "about a Longridge wire gun, said to have been made at Aboukoff, which had fired 1,500 rounds, and which was reported to have been made in half the time and at two thirds the price of those now in the British service." The result was that the British Admiralty recommended that trials with wire guns should be pushed on, Mr. Longridge having confirmed the Russian statement that such guns could be made in half the time and at half the price of the British guns.

April 26, 1888, a 6-inch Longridge wire gun, which was being tested at the proof butts on Woolwich marshes, burst, blowing away a portion of the muzzle. The construction of this gun with the ruptures at A and B is shown in Figure 14.

In May, 1888, Mr. Longridge wrote me of this accident to his 6-inch breech-loading gun.: "Its projectile of 99 pounds was fired with a 34-pound charge of pebble powder. The projectile moved quite freely in the grooves after it was once entered, and nothing in the way of wedging or jamming took place. The velocity was about 1,850 feet seconds, and the pressure gauge showed a pressure of about 25 tons per square inch. The muzzle ring and about eight inches in length of the cast-iron jacket were blown away to the butt, carrying away a gun-metal hoop that had been shrunk on to the end of the coil, uncoiling a small portion of the wire without breaking it. There was another fracture of the jacket about a foot to the rear of the muzzle ring, but this portion was only moved forward about one half inch in the coil. As the tube and coil were perfectly free to move forward in the jacket, except in so far as they abutted against the flange of the steel muzzle ring, it is clear that the whole of the strain which ruptured the gun must have arisen from the tube and coil moving forward, which in fact they did to the extent of about one inch. The causes of this movement were:

"The powder pressure acting upon the difference of area of the obturator and the section of the bore through the grooves.

"The friction of the projectile due to the reaction required to give rotation. The force required to bring back the tube and coil with the jacket in recoil.

"The friction of the products of combustion against the surface of the bore.

"The amount of this last, in the absence of direct experiments, is very difficult to estimate. I feel convinced that the accident to the gun at Woolwich was due to my underestimate of the effect of the friction of the products of combustion, and to a consequent error in the design of the gun."

Toward the end of 1891 Mr. Longridge sent me a copy of his letter to the London *Engineer*, in which he said: "It is in Russia only that my system has had a fair trial, and this is due to the energy and perseverance of Admiral Kolokoltzoff, chief of the Aboukoff works. You express a wish for definite data up to the present time respecting the first wire gun made in Russia. The gun was a 6-inch gun, breech-loading, with interrupted screw and De Bange obturator; length over all, 17 feet, 6 inches; weight, $5\frac{1}{2}$ tons; made at Aboukoff in 1888. After firing 1,000 rounds, with charges of $39\frac{1}{2}$ pounds and projectiles of

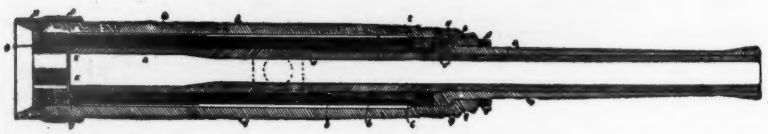

FIG. 15.

122 pounds, the gun was taken to pieces and a new A tube taken, to which the same wire coil, jacket, breech apparatus, and so forth were applied. The gun was then fired 500 rounds, and the authorities being perfectly satisfied, the firing was not carried further. The operation of taking to pieces and rebuilding the gun was very quickly and easily performed, and the cost was practically that of the new A tube only, about one fourth part of the weight of the gun. Since then they have made eight more 6-inch wire guns at Aboukoff, all of which have been perfectly successful, and thirty-two more have since been ordered by the Russian government. Guns of larger caliber are also under consideration, and in a recent letter from Admiral Kolokoltzoff, he speaks very confidently of their adoption ere long. I may perhaps also mention that experience has already proved the great economy of cost of the wire system over the forged steel guns and their much greater rapidity of construction. At last wire guns are recognized even at Woolwich. They are now making sixty of such guns. They are using my formula and are adopting my principle of separating the lon-

gitudinal from the bursting strain (Figures 15 and 16); they are, in fact, practically making use of the principles which I have been advocating for nearly thirty-five years and which have proved to be correct."

Mr. Longridge claims that the government will save from 30 per cent. to 33 per cent. in first cost, besides having much stronger and safer guns. The section of wire to be used is rectangular, $\frac{1}{4}$ inch by $\frac{1}{16}$ inch. Its ultimate tenacity is 100 tons and its limit of elasticity 65 tons per square inch. The Longridge patents are, I believe, now owned by Messrs. Easton and Anderson, of London.

Germany has recently built a few wire guns that are reported to have given favorable results.

In France considerable attention has been given to the subject, and a number of guns have been manufactured; but the failure of the

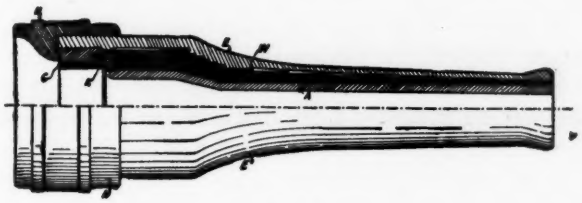

FIG. 16.

34 cm. (13.4″) gun made at Fives-Lille in 1882 and the successful production of "hooped" guns have combined to stop any active development in the direction of "wire" methods.

Although large sums of money have been appropriated for this purpose, the Departments of the United States have not prosecuted this branch of gun construction with much activity. In 1882 General Benet called the attention of Congress to the serious consideration which artillerists in France and England were giving to the system of construction covering the use of steel wire or ribbon, and several boards subsequently recommended the manufacture and test of several guns of this system. Dr. Woodbridge having been given the credit of priority of invention, and being an American, his plans were adopted and followed until very recently, when two new types, the Crozier, called the Department gun, and the Brown Segmental Tube Wire gun, were recommended for test. The consequence is that one Woodbridge gun was tried and failed, another has been condemned as being of too low

power, and three others await trial and completion. One of these is a 5-inch Navy breech-loading rifle, awaiting brazing and test. These together with the Crozier and Brown constitute our experimentation in wire-wrapped ordnance. Other systems and types have been suggested, but difficulties of various kinds have prevented their completion.

The Board of Ordnance and Fortification, in its report for 1892, states that the Crozier wire-wound 10-inch breech-loading rifle, also known as the Ordnance wire-wound gun, being made from designs of the Ordnance Department, is approaching completion at the Army Gun Factory at Watervliet. This gun, as stated in the former report, consists of a steel tube, overlaid from breech to muzzle with a practically continuous covering of steel wire wound in layers, with a jacket cylinder enveloping the steel wire over the reinforce and a continuous layer of steel hoops covering the wire from the trunnion band forward to the muzzle. The coils of wire are electrically welded end to end, so that the gun is wound with a continuous strand of wire. The breech mechanism is of the usual service type. This high-power gun will be completed, and will doubtless be tested, during the coming year.

Captain Crozier advocates the use of castings for the jackets, but in this particular gun I believe the jacket is a forging. The general idea of the type is to have the wire as little interrupted as possible by hoops, etc., between the breech and the muzzle; to have the jacket take the longitudinal strain; and to so arrange the general construction that no part except the tube need be of expensive material, without any sacrifice of strength thereby.

As already stated, Dr. Woodbridge presented plans for the employment of wire in the construction of a gun as early as 1850, but the patent granted him in 1882 describes his present type in which "a cylinder composed of longitudinal bars or staves" is provided as "the chief resistance to longitudinal strains." Describing the wire he says: "It should be either square or flat with a rectangular cross-section; should be 'tinned' or coated with a metal of low fusibility capable of being used as a solder. This serves as a preparation for soldering, or as a protection against oxidizing and to increase the resistance to slipping of wire upon wire." The wire drawn by the John A. Roebling's Sons Company for the Woodbridge guns was $\frac{1}{10}$ inch square section (about No. 12 of their wire gauge) and gave an average tensile strength of about 170,000 pounds. The wire was tinned for brazing.

The Board on Heavy Ordnance and Projectiles reported in 1882 that: "A gun of 10-inch caliber, after the design of Dr. W. E. Woodbridge, was recommended for construction by the Board on Heavy Rifled Ordnance. This device involved a steel tube to be bound around by steel wire under the requisite tension, and to be united by brazing with bronze. The gun was constructed at Frankford Arsenal and submitted to a trial of 93 rounds, 83 of which were fired under the direction of this board. It burst into two parts (under longitudinal strain) just behind the trunnions, under a powder pressure of about 80,000 pounds to the square inch as measured by the Rodman gauge." The projectile weighed 390 pounds; powder charge, 75 pounds.

A 10-inch breech-loading rifle, cast-iron wrapped, was completed at the Watervliet Arsenal in 1891. This gun has a length of bore of 28 calibers, and weighs about 28 tons.

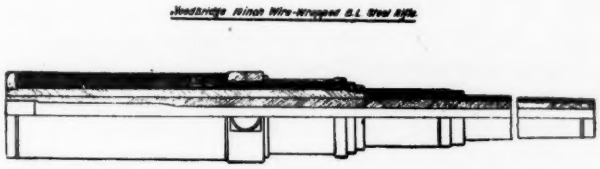

FIG. 17.

The Board of Ordnance and Fortification reported in 1892 that the gun has been fired 161 rounds and the test regarded as completed. It has thus far stood the tests to which it has been subjected, yielding velocities of 1,840 feet per second with a charge of 160 pounds of powder and a projectile of 453 pounds; they consider that the muzzle energy of the gun is so much less than that of the steel gun and the erosion so much greater that the Board for Testing Rifled Cannon does not recommend it as suitable for service under present conditions.

The 10-inch wire-wrapped breech-loading steel rifle built under the supervision of Dr. Woodbridge is practically completed. It (Figure 17) consists of a continuous steel tube, overlaid throughout its rear half with a cylinder of closely fitted steel staves, the whole wound with tinned steel wire, to be soldered or brazed in an oven. The whole length of the gun is divided into three sections by steel rings or bands, and forward of the staves the wire is wound directly upon the steel tube. It weighs 30 tons; is 27 feet long; the projectile weighs 600

pounds. The staves were annealed at the Washington Navy Yard. They were 24 feet long, four inches square, and weighed 1,290 pounds each.

The tension of the wire of the Woodbridge gun is adjusted and automatically regulated by a wire-tension apparatus patented by Dr. Woodbridge in 1885. The tensions of winding for the different layers are intended to give, when the interior pressure shall reach a little more than 80,000 pounds per square inch, an extension to the wire overlying the chamber, in all its parts, equal to that due to a tension of 100,000 pounds per square inch in a "free" wire.

There are two features to the construction which Dr. Woodbridge considers important: to so machine and shape the longitudinal staves as to obtain a condition that will allow the employment of the whole contractile effort of the wire in opposition to the interior pressure, instead of having the resistance of the staves taking a share in it; and to winding wire with a curvature in order to reduce its tendency to unwind if cut. The accomplishment of the former would be accompanied by many mechanical difficulties, while the latter would scarcely seem to meet all the conditions of protection needed against the attack of heavy rapid-fire guns.

The correspondence of G. R. Lindsay and Lieutenant Whistler in issues of the New York *Times* of March 31 and April 5, 1891, relating to a prototype of the Brown wire-wound gun having existed thirty years ago, led me to look into the early histories of gunmaking for a segmental tube gun.

To show that the principle of using longitudinal segments or bars strengthened transversely is not new, I have presented some sketches of firearms of the period of 1330, taken from an *Elementary Treatise in the Forms of Cannon and Various Systems* translated in 1832 from the French of Prof. N. Percy, of Metz. In describing them he says: The first firearms, which were called bombards and cannon, were fabricated of iron. These arms were very short and of a great caliber, and were made of bars of iron arranged in a cylindrical form and bound together by bands of the same material. They projected pieces of iron and stones, and were fired under great angles. Subsequently they were forged in a single piece, and among the most remarkable of this period, some had outside and inside the form of a frustum of a cone (Figures 18 and 19), the small diameter corresponding to the breech which terminated in a conical screw (Figure 19); others had

the form of a cylinder, or were reinforced throughout a great portion of their length towards the muzzle. Some of these had a chamber for powder, and their reinforce extended throughout the length of the bore (Figures 21 and 22); the bore was eight times the diameter in length, which was 13″; the width of the chamber was one third of the

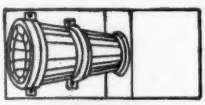

FIG. 18.

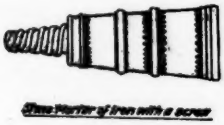

FIG. 19.

FIG. 20.

diameter of the bore, and the depth of it four thirds. All these arms were strengthened by a swell at the muzzle and breech, and by bands at different intermediate points. They had neither trunnions nor handles. According to Thieroux, the first cannon were conical and shaped like an apothecary's mortar or vase (Figure 20); they were called mortars, vases, or bombards. The first change was to a chambered gun with a cylindrical bore, but the chamber was of a less diameter than the bore (Figures 21 and 22). Because these cannon fired stone projectiles they were called *perrieres*. They were made of iron bars bound together with bands like a barrel.

Mr. Brown claims that the fundamental principle of his gun lies in the segmental tube and not in the wire wrapping. He has never

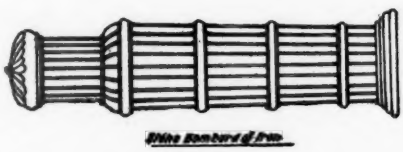

FIG. 21.

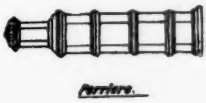

FIG. 22.

asserted that he was the inventor of the wire gun, nor that the use of the segmental tube was new; but he believes that the idea of subdividing a core for the purpose of obtaining special elasticity is original with himself, and that thereby it is possible to set up such a high degree of initial compression that even under the highest powder pressure the compression at the surface of the bore will not be reduced to

zero. To present the views of the advocates of this principle of gun-making, I have taken the following description from the literature of Lieutenant Whistler, the company's engineer:

"The Brown Wire Gun (Figure 23) consists essentially of a segmental core wound with wire under such tension that the compression between the longitudinal segments of the core induced thereby will be more than sufficient to resist all ordinary powder pressure. The longitudinal segments are primarily held together by a breech and muzzle nut screwed on hot, with the proper degree of shrinkage, so that the tension of the nut and adjoining wire will be the same after winding. The wire is wound between the nuts under a high degree of tension, and anchored by a special device. The trunnions are not attached to

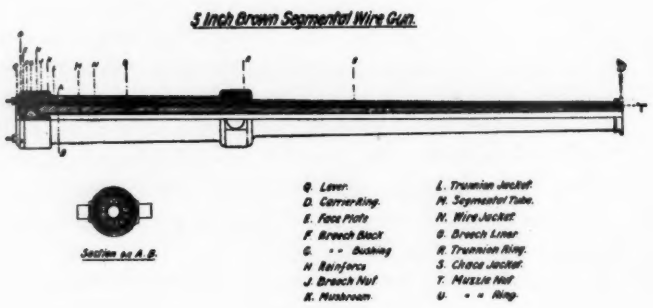

FIG. 23.

the core or body of the gun but to an outer trunnion jacket, which jacket is attached to the gun proper by means of the breech nut. By this means the recoil is transmitted to the trunnions through the breech nut and jacket, and the core or body of the gun is thus relieved from the major part of the longitudinal thrust due to powder pressure upon the bottom of the bore. The gun itself is free to expand longitudinally within this jacket, which is attached only to the breech nut. The essential feature of the gun is, of course, the segmental core. This core consists of a number of longitudinal steel segments, the number being so regulated that the maximum thickness of a segment shall not exceed one half inch materially. . . . The chase jacket consists of a series of interlocking hoops shrunk on over the wire extending from just in advance of the trunnions to the muzzle, the entire jacket being

held in place by a muzzle nut, the thickness of which and the amount of shrinkage being so adjusted that when completed the compression produced by the built-up muzzle nut will be the same as that produced by the wire and chase rings."

During the progress of the work, which has been extended over a period of three years, mechanical difficulties and the results of the trials of experimental cylinders representing sections of the powder chamber gave reason for decreasing the number and increasing the size of the longitudinal segments and the necessity for the insertion of a lining tube to prevent the entrance of the powder gas between the segments, which, in the case of one of the experimental cylinders, was so great as to cause marked discoloration at the joints. The lining tube was inserted under initial tension and extended to about five or six calibers in advance of the front end of the chamber. This tube can be removed and replaced by a new one whenever it becomes too much eroded for service. Recalling the unfortunate experiences of the Maitland half-liners in England, this would appear to be but another invitation for the erosive action of the powder products.

The advantages claimed for the system are: "1. In consequence of the small weight of each of the component parts of the gun, crucible steel can be used economically. 2. The small size of the segments and the ingot from which they are rolled admit of being carefully cast and uniformly forged, so as to insure uniformity of metal, and of being thoroughly annealed. 3. They can be readily rolled into shape; that is, the method of construction is exceedingly economical. 4. They can be thoroughly and conveniently inspected. 5. The size and thinness of each segment insure a thorough and uniform tempering and annealing, if temper be considered desirable. 6. The size of the segments admits of readily setting up conditions of special elasticity by cold work. This latter feature is by far the most important one in this system of construction, as it renders it possible to use a character of steel far beyond anything heretofore employed in the core of a gun."

If the segments compressed by the full elastic strength of the wire present an interior surface that can withstand the erosive action of the powder products, we must admit that Mr. Brown has supplied a method of forming the bore of the gun which has decided advantages; but if recourse has to be had to a liner to resist erosion we return to a core that will not sustain the full elastic strength of the wire, and it prob-

ably will be more economical to use a steel tube of suitable dimensions than a combination of segments and thin liners, unless these liners, like the segments, are cold drawn, and thus by a great amount of mechanical work rendered impervious to the serious ravages of the powder products.

Even if the 5″ experimental gun now approaching completion successfully meets all the conditions that its projector and engineer claim for it, it will still remain to be proved if all the mechanical conditions can be met in guns of larger calibers. The experiment is an interesting one, and if the type is not absolutely new the method of construction is, and all the theory in connection with it is being ably and fluently presented.

Through the courtesy of the John A. Roebling's Sons Company, of Trenton, New Jersey, Messrs. R. H. Wolff & Co, Limited, of Harlem, New York City, and First Lieut. G. N. Whistler, of the United States Fifth Artillery (the engineer of the Brown Gun Company), I am able to show you samples of the wire used in the construction of the Woodbridge and Brown guns.

Dr. Woodbridge and Lieutenant Whistler have also been good enough to answer freely many of my recent questions. They, together with Captain Crozier, have shown much interest in your desire to have this subject presented to and discussed by your Institute, and I regret exceedingly they could not be present this evening to answer any questions that my lecture may have suggested.

It is evident from the various plans and suggestions I have called to your attention that very few attempts were made to apply the individual parts to a service of their individual and separate capacities, and that the attempts to unite in one mass the integral parts resulted in impairing the integral strength and a consequent reduction in the strength of the whole. This separation, however, has been successfully accomplished in the Longridge gun (Figure 15) and mortar (Figure 16), and it is being done in the "hooped" system as well.

In the de Brynk construction the tangential strength may be provided by wire-wrapping without interfering in any way with the advantages claimed for it; namely, turning the core of the gun upon its main axis when the scoring of any part renders such operations necessary, separating the gun into masses to facilitate transportation and assemblage and to decrease the size of the machinery required for the manufacture of its parts.

All accidents to wire-wrapped guns point to the absence of adequate longitudinal strength. After a careful consideration of the many devices that have been suggested to meet this defect, that of supplying this quality by long forged steel hoops seems the simplest and most effective.

When considering the argument so often presented that there will be a saving of weight, remember that the reduction of weight in the gun must be provided for in carriage and recoil, and that we have now replaced the expression "heavy ordnance" by that of "high power ordnance," because we have gained the power without additional weight of metal, and in many cases by a marked decrease of it. All welding can now be done by electricity; weak spots can thus be avoided and continuous winding easily effected.

When many of the objections to wire-wound guns were raised wrought iron and iron wire were generally employed, and the mechanical means of shaping and machining were more or less imperfect. Whitworth used some steel, and his mechanical devices led the world but were infants in comparison with present appliances.

The advantages claimed for the wire system of construction are:

1. That steel in small sections can be obtained that possesses greater strength than is possible to get in any other form.

2. That each layer can be brought truly to its correct tension.

3. Flaws of manufacture can be easily detected, and if not discovered are confined to that part in which they exist.

4. The parts of the gun are light and can be more certainly and easily produced and assembled.

5. For their manufacture, expensive and complicated plants are not needed.

In comparing the reported results of the tests of the various types we must not forget that these experiments have been carried on in various parts of the world, in places very far distant from each other, under different methods, inventors, and circumstances. In the majority of cases they have required to produce them much special machinery which if employed in subsequent production would materially reduce the cost of the guns turned out. In some cases the inventors have been employed to superintend or advise concerning the construction or the preparation of tools or machinery necessary to carry out their special and in some cases peculiar ideas; all these circumstances

have combined to make the cost of the experimental guns very great. On the other hand, the inventors or advocates in estimating the comparative cost and time of production have given themselves every benefit. As these guns have never become commercial service products on any large scale (I believe Russia has manufactured a larger number than any other nation), it is impossible to make any reliable comparison of their cost and the time required for their production.

The wire-wrapped type had the honor of firing the "Jubilee Rounds" in the Queen's Jubilee Year, and gave wonderful results. On April 16, 1888, was fired at Shoeburyness the first of a series of rounds intended to investigate the conditions attending firing at very long ranges. The gun selected was a 9.2″ gun, made under the direction of General Maitland in the Royal Gun Factories. The weight of the gun was 22 tons; that of the projectile 380 pounds, which, fired with a charge of 270 pounds, gave a muzzle velocity of 2,360 feet seconds. The elevation of the first round was 40°. The projectile fell at a range of about 21,000 yards, or nearly twelve miles. On July 12, at 43° elevation, a range of 21,600 yards was attained, and on July 26, with 45° elevation, the range was 21,600 yards, or about 12.4 miles. The projectile remained in the air about 69.6 seconds, and its trajectory reached a height of 17,000 feet, or about 2,000 feet higher than the summit of Mont Blanc.

Comparing the velocity, however, with a more recent 6-inch quick-firing gun (hooped) a velocity of no less than 2,669 feet has been realized with a 19½ pound charge of cordite.

It is easier for the historian to criticise than for the engineer to prophesy; consequently we should not only be grateful for the failures upon which many of our successes have been based, but also remember that the constructions which subsequently proved so inadequate were marked improvements over those which went before. Further, they should be looked upon and their value estimated from a standpoint and comparison of the periods in which they were suggested. Lecky in his *The Art of Writing History* said: "A fatal and very common error is that of judging the actions of the past by the moral standard of our own age." Scientific accomplishments at present are like clearing-house settlements — completed to-day only to be changed to-morrow.

FIRE-PROOF CONSTRUCTION.

By N. POULSON, of the Hecla Iron Works.

Read February 23, 1893.

The object of the mode of fire-proof construction to be described is to build more economically than is now done. In the present construction, with columns, girders, beams, arches, etc., there is a great waste of material which cannot be avoided. In the arch construction there need not be any waste material, and the material used is used to a better advantage. The construction is as follows: In a building in which the floors are supported upon columns metal arches and their ties are built between the columns in such a way that the strains, compression, and tensile are taken care of in each bay or floor between columns, so that there will be no horizontal thrust on either columns or walls from the floor. The arches are made of bar L or T iron or steel. If the floor is to be supported on four girders or four walls there is placed on the lower flanges of the girder or on the walls a polygon-shaped frame, from the corners of which are sprung metal arches, and where the arches cross each other they are held together with U bolts. The arches will form a metal dome, of which all the strains from the arches are taken up by the polygon ring, so that there will be no horizontal thrust on the girders or walls from the arches in the floor construction.

This completes the metal part of the construction. The plaster or cement part of the construction is made as follows: For a plain ceiling with the metal arches showing underneath there are placed in the spaces between the arches air-cushions, which are pressed up against the metal arches from underneath; the air-cushions will then form a dome in each space between the arches; on top of the air-cushion is spread plaster of Paris or cement; after it has set the air-cushions can be removed and the under side of the ceiling will be

finished, showing a groined ceiling. But if the metal arches are to be covered with plain or ornamental moldings they are first put up and then the air-cushions inserted between them. If the domed panels are to be ornamental a flexible mold is placed on top of the air-cushion, and the flexible mold may be made of rubber, gelatine, or

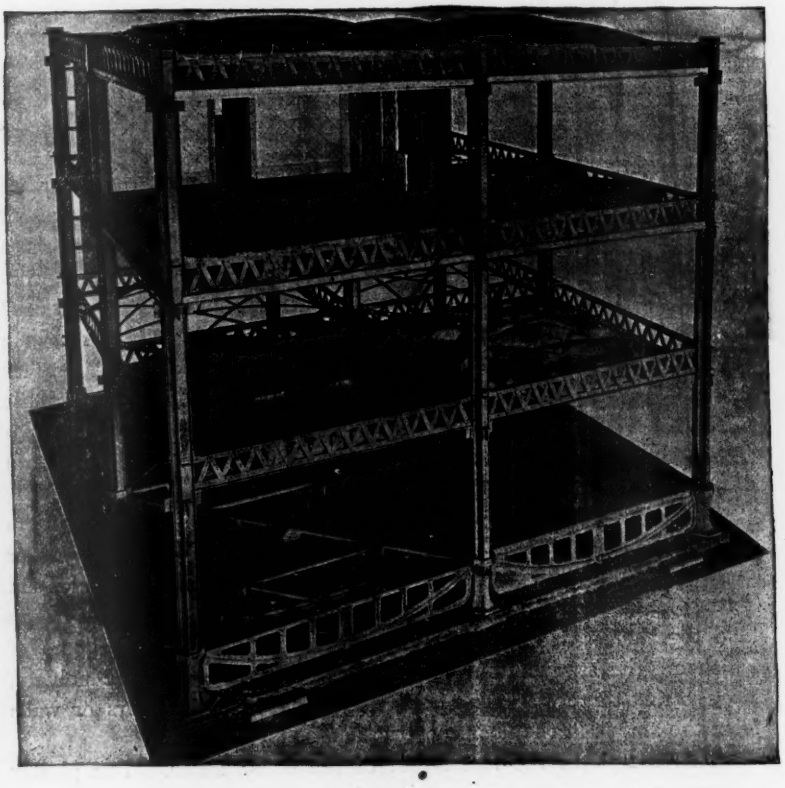

FIG. 1.

any such material. After the under side of the ceiling is finished there are constructed on top of the iron arches cement arches or ribs. They are formed by placing two boards parallel with the metal arches five or six inches apart; the space between the boards is then filled with concrete; in these ribs may be left circular holes through

which hot air may circulate and thereby heat the floor. After the ribs are made and the boards removed, wire and wire netting are

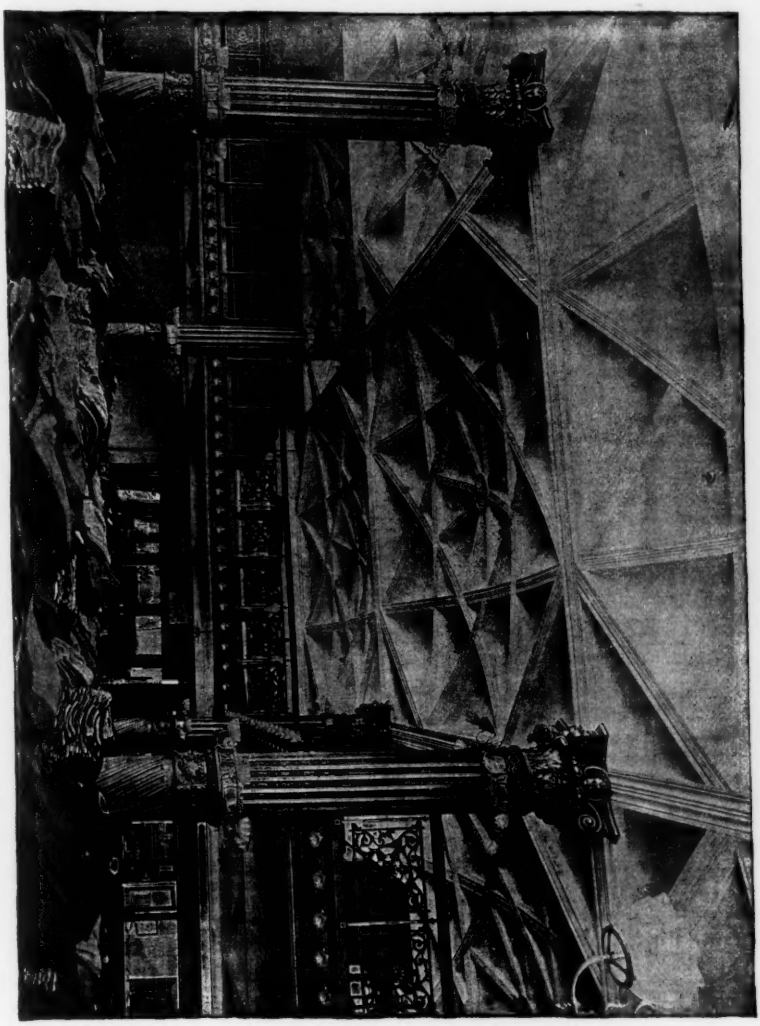

FIG. 2.

stretched over the cement ribs, and on top of the wire netting is spread concrete about three inches thick. This finishes the floor, except the finished floor of wood, tile, or cement.

Let us compare the cost of this construction with that of the usual fire-proof floor construction, composed of girders, beams, brick

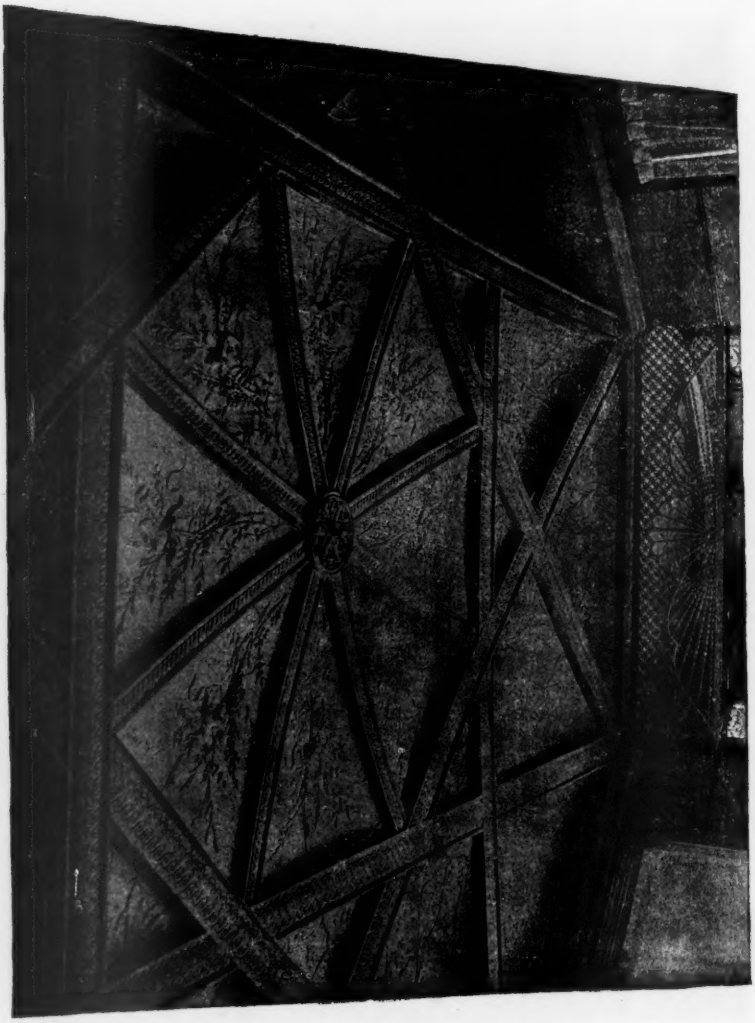

FIG. 3.

arches, etc., in which there is a great waste of material. In the case of a floor constructed of beams, girders, etc., to carry 150 pounds per square foot, the load is first supported by the beams, by them trans-

ferred to the girder and from the girder to the column; that is, the same load is carried twice before it reaches the column. The brick

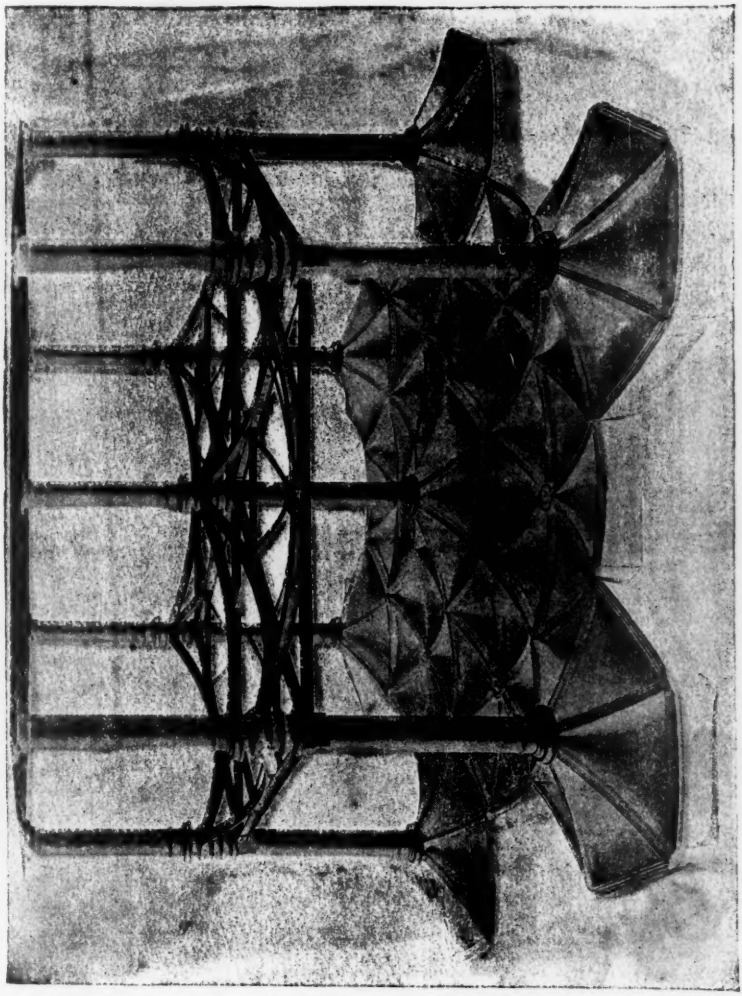

FIG. 4.

arches, filling over them, plastering, etc., have also first to be carried by the beams and then by the girder; that is, for supporting a load of 150 pounds there has to be provided metal sufficient to carry 450

pounds. If the load of 150 pounds was only carried once, and there was no dead load of brick arches, etc., it would only cost 33.3 cents for iron where it now costs $1.00 to support the resultant load, which

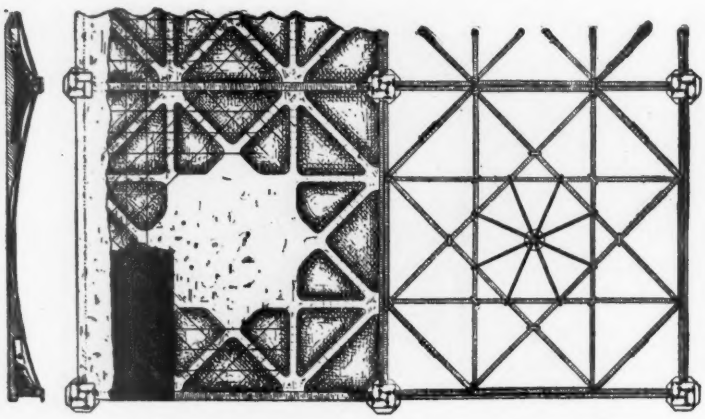

FIG. 6.

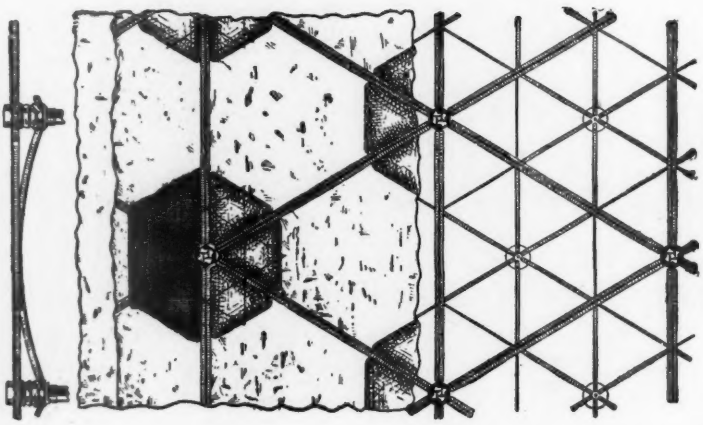

FIG. 5.

is equal to three times as much load required to be supported, and if the iron beams could be made with the web lighter towards the center and the flanges lighter towards the ends of the beam, there could be saved of the metal in the beam at least 10 per cent., without

reducing the strength of the beam, which would reduce the cost to 30 cents; if there was used for supporting the load bar L or T iron instead of beams, the cost could be reduced 20 per cent., as the bar

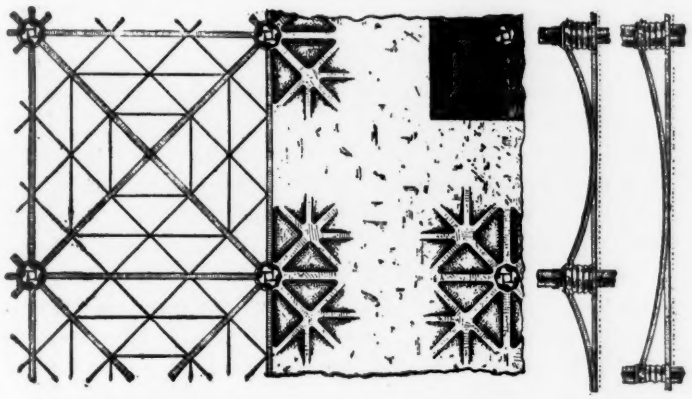

FIG. 7.

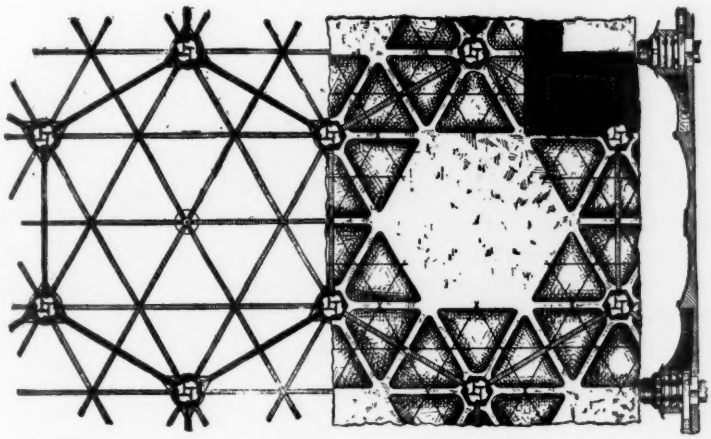

FIG. 8.

L or T iron costs 20 per cent. less per pound, which would make the cost 24 cents. If the above is calculated for a floor with 12″ beams, by making the beam 24″ high instead of 12″ the same amount of iron will carry twice as much, or the amount of iron could be reduced

one half, which would make it cost 12 cents, or if made 36 inches high it would reduce the cost of iron to 8 cents instead of $1.00. The above conditions cannot be met by the beam and girder construction, but can by the arch construction; there the dead load is self-supporting; the load is only carried once. Bar L or T iron is most suitable for the construction of the floor, and can have two or three feet of rise without reducing the cubic air space in the room below.

The cement and plaster part of the construction will also cost less than the usual brick arches, because there is less material used and it is of less costly nature; and furthermore the labor is quickly performed, as it merely consists of spreading the materials in their proper places.

The columns are made of wrought iron or steel, and are continuous from the foundation to the roof, but diminish in amount of materials upwards in proportion to the loads they have to support. In starting at the foundation with a column made of four 12″ heavy beams, after one or more stories the beams can be reduced to 12″ light beams; after that to 12, 9, and 6 inch channels. The horizontal joints are all spliced joints, so that the columns form practically one column from foundation to roof, thereby making the columns much stronger and stiffer than with the same amount of material in a number of short columns placed one on top of another. The continuous column is also more economical to make, as the metal can be of a uniform length and holes punched alike in each piece, so that a beam or channel cut to uniform length will fit in any column. The only place where there will be any waste is at the top of the column, where they may have to be cut to irregular lengths. This way of building a column has a great advantage, as it leaves four continuous recesses from the foundation to roof, which space can be utilized for pipes and wires. If the column is made to finish a few inches above the roof, and a removable cap put upon it, pipes may be put in or removed from the recesses in the column at any time.

LIST OF ILLUSTRATIONS.

No. 1 shows the different stages of the construction described. The basement or cellar shows inverted iron and cement arches with the level floor above, and the space between the arches and the floor can be utilized for piping, wiring, or flues, and can be gotten at at any time. The floor above shows the plaster domes as they are cast over the air-cushions. It also shows the cement ribs for arches running parallel over the iron arch bars. The story above shows the finished floor, and the top story shows the domes of the finished roof. It also shows the continuous iron or steel column with recesses for piping and wiring.

No. 2 shows an interior view of the Smith & Randolph Building, in Brooklyn, in which this construction was used.

No. 3 shows a finished ornamental ceiling. In making this an ornamental gelatine mold is placed on top of the air-cushions.

No. 4 shows a construction in which neither beams nor girders are used, but arches with their ties sprung from column to column, and in the three-cornered spaces between the main arches there are again sprung smaller metal arches. The upper part of the figure shows the under side of a finished ceiling.

No. 5 shows an arrangement of columns and metal arches in triangular construction. It also shows the cement part over the arches, with the wire and wire cloth stretched to receive the cement for the finished floor.

No. 6 shows a square construction with girders between the columns and the octagon dome built between the girders. It also shows the cement ribs and the wire above to receive the cement floor.

No. 7 shows a square construction with no girders, but metal arches between the columns, and with smaller arches in the triangular spaces between the main arches. It also shows the cement ribs and wire and wire cloth to receive finished floor.

No. 8 shows a hexagon construction, with two metal arches springing from each column and the tie rod from column to column so as to form a ring around the hexagon space. It also shows the cement ribs and wire and wire cloth to receive finished floor.

HIGH FREQUENCY ELECTRIC INDUCTION.

By ELIHU THOMSON.

Read March 9, 1893.

It is my purpose in the present paper to give an outline of some experimentation with electric currents of high rate of change or high rate of oscillation compared with the rate of ordinary alternating currents. These latter alternate their direction of flow from 100 to 250 times per second, or the current is composed of waves or pulses reversed in direction at that rate. We therefore speak of 100 to 250 alternations; or, as it requires a double reversal to make a complete wave, we speak of a periodicity or frequency of 50 to 125. Fifty waves per second would be a comparatively low frequency current; five thousand to ten thousand, a moderately high frequency; and hundreds of thousands to many millions may be called high and very high frequencies comparatively speaking. Still, all things are relative, and in the light wave or radiant heat wave we have electrical oscillations of frequencies as great as hundreds of millions of millions per second. If we have two conducting plates separated by an insulating space, and charge one plate positively and the other negatively, we have a simple type of what is called a condenser. The insulation may be air or other dielectric, such as glass or hard rubber. We have in the Leyden jar the earliest form of condenser, and for certain purposes still the best form of this useful electrical device. The charged thunder-cloud layer separated from the earth by a layer of air forms with the earth surface a huge condenser, and the earth strokes or lightning flashes between earth and cloud are the discharges of such condenser. If in a condenser the charge is sufficiently increased in potential difference between the conducting plates or the plates brought near enough together, or if a wire be run from one plate near to the other, a discharge takes place in the form of a spark and there is also an equalization of charge of the plates. The spark simply indicates a breaking

down of the medium separating the plates and its momentary conversion into a conductor composed of hot gases and metallic vapors joining the two plates where the spark existed.

It was formerly thought that in equalizing the charge or combining the positive of one with the negative of the other in such a discharge of a condenser the spark represented a single rush or flow of electricity. Long ago, however, Professor Henry was led to the conclusion that these discharges were of oscillatory character and that the action of discharge resembled that of the release of a bent spring which only comes to rest after a number of more or less rapid alternations or to and fro movements. More recent investigations have settled conclusively the fact that the condenser spark represents in most cases, though not always, an electrical vibration or oscillation of charges, an alternating current of high frequency lasting for a fraction of a second, in which fraction of a second the direction of the current has reversed many times with diminishing force. Prof. J. T. Trowbridge, by means of a rapidly revolving mirror and other ingeniously devised apparatus, has obtained most beautiful photographs of such discharges showing in the most perfect manner the oscillations of current referred to. Now, if a condenser of a certain capacity, as it is termed, be discharged over a short path, the rate of its oscillations of discharge will be greater than when the path or wire through which it is discharged is long. And if the wire forming the path of discharge be of good conducting material and wound into a simple coil of very many turns, the frequency or rate of oscillation of the current of discharge will be much further lowered. Indeed, in this way it is possible to give to the discharge any desired rate within reasonable limits. From a rate of hundreds of thousands per second it may be brought down to less than one thousand. By the addition of the coil in the discharge circuit we have brought into play a property called inductance, which acts to slow the rate of discharge.

If a current be suddenly passed through a coil of wire, it meets with an opposing force which tends to delay its passage, owing to the fact that around the coil and through its axis there must be some work done in producing magnetism in the medium. On an attempt being made to cut off the current, the magnetism in disappearing sets up an action which tends to prolong the current and prevent its change. These are the actions of self-induction, more recently called inductance. An iron core or bundle of iron wires increases the value of the inductance very greatly.

Early experimenters frequently passed Leyden jar or condenser discharges through coils of wire and noted the effects, the chief of which was to flatten or deaden the sharp snap of the discharge. To-day with a sufficiently long coil we may cause the discharge to take any pitch and become audible, if we please, as a musical tone.

Early experimenters, notably Professor Henry, even placed alongside the coils through which condenser discharges were passed other coils and received the inductive discharges set up in the parallel coil, thus realizing in embryo an induction coil, the primary coil of which was given an oscillating condenser discharge, while the secondary currents obtained in the parallel coil were noted by simple means.

In 1877 I made similar experiments in passing the discharge of a number of large Leyden jars through the primary or secondary of a Ruhmkorff coil and noting the effects in the other coil. The effects were in some cases high frequency effects, though scarcely recognized at that time. But we have in the Ruhmkorff coil itself an excellent example of an apparatus in which a charged condenser discharges at a high rate through a primary coil and induces a very high potential discharge in a long and fine secondary coil placed outside the primary.

It has often been stated in the books that the function of the induction coil condenser, which has its conducting foils respectively connected on each side of the break piece which interrupts the current of the battery passing in the primary coil, is simply to prevent spark at the contacts of the interrupter by absorbing or taking up the extra current which would otherwise appear as spark. This is incomplete and erroneous, as may easily be proved.

The ordinary induction coil has its primary coil, its secondary, interrupting contacts for the primary, condenser around them, and battery with rather short conducting wires, and may be assumed to work normally and give a high potential spark between its separated terminals at every interruption of the primary coil and battery circuit.

Now let us extend the wires of the battery to a very considerable length, or coil them in separate open coils, yet keep them of large enough size so as not to weaken the battery current by increase of resistance in its circuit. On working the coil and adjusting the condenser to get rid of spark, we find the activity of the secondary lessened. It can, however, be restored by connecting a large capacity condenser, or better, a cell with plates of lead immersed in dilute sulphuric acid across the battery wires near the coil. Moreover, for a

Ruhmkorff coil to give its maximum effects the condenser chosen for it must have a definite size or capacity depending on the proportions of the primary coil and core and the electro-motive force of the battery. The real object of the condenser is to obtain the benefit of a high frequency reversal in the primary coil, that is, to confer the high period oscillatory character of the condenser discharge on the primary current, and so get enormously increased inductive effects in the secondary wire.

This effect of inducing discharge in the secondary wire depends on a magnetic change or loss of magnetism in the iron wire core or bundle in the center of the coil. Upon the interruption of the primary circuit the condenser receives a charge from the primary wire which instantly discharges itself in the reverse direction through the primary, and as a consequence quickly discharges and tends to reverse the magnetic state of the core. The more quickly the reversal takes place, other things being equal, the longer the spark obtainable from the secondary circuit terminals. Lengthening the wires to the battery delays this reversal by interposing more self-induction, which, as stated above, is a cause of reduced speed or rate of oscillation of the condenser discharge.

As, however, when the lead plate cell is used as a shunt to the battery wires near the coil, the reversal may now be confined to a local circuit including only the primary coil and the shunting cell with its lead plates, and it will be seen that the effect of long battery wires may thus be almost completely counteracted. It does not follow that the secondary discharge of a Ruhmkorff coil is oscillatory even when the primary tends to be so, for the very high resistance of the secondary circuit will probably prevent the flow of more than a single pulse of current in one direction at each break of the primary circuit.

Having stated the conditions under which we may expect to work successfully, we may now be prepared to simplify our apparatus. Let us take a Leyden jar, or battery of jars, charged, say, to give one half inch spark between its terminals, one from the inner coating and one from the outer coating, and interpose a coil of a few turns of wire in the discharge path or circuit. Upon a discharge passing, an exceedingly rapid to and fro current passes in the coil, the turns of which must be kept well apart or a leap from turn to turn will take place in the effort of the current to avoid going around. Now place another coil parallel to the first, and let these be of an equal number of turns,

but well insulated from the first. On passing the discharge through the first coil a similar discharge may be obtained between the separated terminals of the secondary coil.

Let the secondary coil be replaced by one of, say, twenty times the number of turns which the first coil has, and the discharge be sent through the first. In this case it will generally be found that the second coil gives evidence of very powerful induction, but that it requires to be immersed in oil to preserve its insulation. This is done by placing both coils in oil and repeating the experiment. Now the terminals of the secondary coil may yield sparks of several inches in length even though the condenser jars may only give one half inch. But what have we here? Merely a Ruhmkorff induction coil with a condenser charged to 20,000 volts perhaps, as against one charged in ordinary cases to less than a hundred volts. It is no wonder then that we may use a secondary of only a few hundred turns of wire as against one of many thousands of turns in the ordinary Ruhmkorff induction coil and obtain the same or a greater length of spark. I have an apparatus of this kind with ten turns of coarse wire in its primary wound as an open single layer coil, and 300 turns of secondary, also a single layer, both immersed in an oil box. On passing condenser discharges of 20,000 volts in the primary it will give very long sparks from the secondary. The turns of the primary are selected to give the heaviest current and highest rate of oscillation of the discharge with as many turns as possible; in other words, to obtain a convenient maximum. It is inconvenient to charge the condensers and use only a single discharge at a time. To obviate this I have recourse to a modification of a method which I first applied in 1881, that is, to use a dynamo current of alternating character to keep charging the condensers as they are discharged. I found that I could so use the dynamo current as to cause condensers to rapidly charge and discharge over a spark gap, and that a coil in circuit with the condenser needed to have its turns kept apart an eighth of an inch or more, even though the wire was well covered with paraffined cotton. The inductive effect of the coils in the condenser circuits was very high, and I was convinced at the time that we had to deal with discharges of very high rates of change. In applying dynamo currents to the charging of a condenser we may therefore use an alternating current of, say, 75 volts potential and of low period or low frequency, such as ordinary lighting currents, and by an induction coil or transformer raise such potential to, say,

20,000 to 30,000 volts in the secondary winding. This high potential current is now used to charge a condenser of suitable capacity, such as a battery of Leyden jars, the discharge circuit of which includes an open coil of but few turns and a space called a spark gap, over which the discharge must leap. An air jet plays upon the spark gap to prevent a continuous arc forming.

To digress for a moment here, it may be mentioned that with a condenser of two or three jars, and a properly directed air jet or wind blowing on the spark gap, some of the most beautiful imaginable effects of electrical discharge are obtainable. Appearances of beautiful striated flames and networks of fine sparks surrounded by purple fire are easily obtained. Also by putting in circuit with the condenser and spark gap coils of very many turns of fine wire, the rate of vibration may be so lowered as to obtain discharges which whistle continually like the notes of a canary, or which are still lower in pitch, or again so high that the note though strong is at the upper limits of audition.

But to return to the coil of few turns, it will be found that the apparent resistance of even a very coarse wire used in the coil is so great that an incandescent lamp may be lighted between one turn and its neighbor, that, in fact, the opposition to the flow of current is so extraordinary that a considerable length of spark may be obtained in shunt to a few turns. Let us pause to consider why this is. The condenser charge on leaping the spark gap tends to pass a very heavy current through the coil, *i.e.*, to discharge instantly. This involves, however, the instantaneous production of an intense magnetic field in and around the coil, which gives rise to a force tending at first to check the condenser discharge and afterwards to prolong such discharge so that there results an over discharge or a charge of opposite character which again discharges, and so on. But these oscillatory discharges may have a rate of hundreds of thousands per second, or a still higher rate depending on the conditions. Every inch of wire in the coil is as active as a number of feet at lower frequencies.

One of the most curious effects producible is that of balanced induction, as when a double coil is used one inside of the other, the turns of which can be so selected that all of the discharge passes in the outer coil or all in the inner. A departure from a definite relation of turns, relatively less or more, destroys this balance of induction.

The inductive action of the high frequency discharges in ques-

tion is quite intense. Electro-dynamic inductions so intense as to generate potentials of a hundred or more volts to the inch of wire are readily obtained, and of course the reaction or self-induction of such a current sent into a circuit is equally remarkable. Conductors which are so heavy that with ordinary continuous currents an ordinary incandescent lamp would be completely shunted offer such an impedance to these high frequency currents that the lamp is brilliantly lighted across a short heavy loop, an experiment due to Mr. Tesla, an early worker in this field. A single turn of wire of, say, six or eight inches diameter of circle, used as a secondary to a few turns used as a primary, suffices to brilliantly light a lamp connected in the circuit of the turn. Such experiments may be modified in many ways.

In experimenting with apparatus in which a very few turns of wire were used with the condenser discharge as a primary, and in which a few hundred turns were used as a secondary, it was found to be necessary to immerse the coils in oil to insulate them and prevent escape of the currents induced in the secondary. These experiments have developed the curious fact that while ordinary oils are capable of resisting puncture by high potentials of ordinary alternating currents when the thickness of the insulating layer of oil is to the air layer as about 1 : 3 or 1 : 4, the relation when high frequency currents are used is about 1 : 40. It was also found that the cleaner the oil or more free from suspended particles the more uniform its insulating power or resistance to puncture and the greater the potential needed to puncture it. Another curious fact was brought out, namely, that under oils discharges between balls or plates took place more readily and through greater distances than between points — a fact which is exactly contrary to what is found in the case of air.

It has recently been found that while alcohol is a partial conductor for ordinary currents it is an insulator for very high frequencies, and it appears probable that water itself, and perhaps ordinary electrolytes, such as a solution of salt, would behave as nonconductors with a sufficiently high frequency applied to them. By taking advantage of the inductive effects of a condenser of considerable capacity discharged across a spark gap or a pair of gaps in series, upon which a blast of air is kept blowing, and having also in the circuit of the discharge say 15 turns of coarse wire wound into an open coil used as a primary, with a secondary coil of a single layer of some hundreds of turns of finer wire wound on an insulated frame or support, and with the pri-

mary immersed in an oil vat, remarkably high potentials are readily obtained. The coils are separated by oil, the thickness of layer depending on its resistance to puncture by the discharge.

In the largest apparatus yet constructed the primary coil has 15 turns wound double of No. 6 wire, and the turns having a diameter of 22 inches, while the whole coil is spread to an open helix of 28 inches in length; weight 14 pounds. The secondary coil is wound on a hard rubber open frame, and consists of 580 turns of No. 26 wire, the turns having 17 inches diameter, and the coil being 28 inches long. It contains about 2,600 feet of wire; weight $2\frac{1}{4}$ pounds. These coils are immersed in an oil vat of wood and are held concentrically. The terminals of the fine wire are carried out at the ends of the oil vat in the center of a trough about 5 inches square filled with oil, and the conductor is so kept covered with oil to the very end where it is at last exposed. In some experiments with this coil, with the terminals 64 inches apart, it gave torrents of sparks between them. The sparks were blue-white, and from the terminals branching forked discharges took place in all directions to distances of two or three feet. These sparks are by far the longest ever produced artificially, and the apparatus is so simple and of such slight cost that it is extremely doubtful whether any such large Ruhmkorff coils as the Spottiswoode coil, with its 280 miles of secondary wire, will ever be made again. With the simple oil insulated apparatus described a torrent of sparks (250 per second) was obtained. Heavy glass plates or slabs of other insulating materials are readily punctured, and where the discharge does not puncture but spatters over and around the slab the effect is very beautiful and impressive. Hard-wood plank is perforated and set on fire, sticks are splintered, and the known effects of lightning are reproduced in a very complete way.

The development of ozone in the neighborhood of the apparatus is very great, and soon renders the air pungent and irritating. It appears from the experience gained up to this time with the apparatus that it would be possible to produce apparatus on similar lines capable of developing electric potentials sufficient to leap the space between electrodes twenty or more feet apart.

Especially striking, also, are the experiments which concern the passage of these high frequency discharges through a person's body. Even with frequencies not higher than two thousand per second the late Dr. Edward Tatum found that a dog could support a greater cur-

rent than if the current were continuous in character. With still higher frequencies it is probable that greater immunity would exist.

By holding a metal or carbon rod in the hand while standing on the floor or seated near the high potential apparatus, and providing small wires and bits of wood suspended from one terminal of such apparatus, while the other is connected on the other side to a length of wire or a metal plate, sparks may be taken between the wire or suspended objects and the rod held in the hand, and these may be a number of inches in length in an apparently continuous stream. In this way the small wires may be melted down and objects set on fire, pieces of wood charred, etc., by the currents passing in the spark and through the person's body. Notwithstanding the striking effects, the current is scarcely felt at all.

By the use of vacuum tubes and plates or wires extending from or connected to the terminals of his high frequency coil, Mr. Tesla has produced very brilliant effects of illumination of such tubes. In fact a vacuum tube may be used to explore the high frequency electrostatic field around the high frequency apparatus very much as a compass-needle may be used to explore a magnetic field. It has long been known that a Geissler tube lying near a powerful Ruhmkorff coil in work would frequently become luminous, but the high frequency apparatus produces all effects obtainable with a powerful Ruhmkorff coil in far greater intensity.

It may be asked why in the construction of the high potential induction apparatus I have selected a primary of only 10 or 15 turns. In answer it may be said that it was found that while a greater number of turns would naturally give a greater magnetic effect, and therefore greater magnetic change and more powerful induction, yet the use of such greater number would so lower the frequency in view of the desirability of using condensers of rather large capacity relatively as to lose more than was gained. The induced electro-motive force depends on the rate of change or frequency, as well as on the total field undergoing change. Again, should we attempt to run up the frequency by still further diminishing the turns, what we so gain is lost in diminished ampère-turns or magnetic field, especially as there will always be a certain impeding inductance in the connections or leads from the condenser plate to the primary coil. This inductance should be cut down as much as possible by the use of wide strips for such connections and by a non inductive arrangement of them where it is possible.

It may be remarked in conclusion that, as concerns the secondary of the apparatus as well as that of a Ruhmkorff coil, the effects are not purely electro-dynamic, but are modified by capacity. In every coil in which high potentials are generated, especially at high frequencies, the electrostatic induction of the turns of the secondary upon each other and upon surrounding or adjacent conductors, particularly the primary coil parallel to the secondary, are not to be neglected. From the center turns of the secondary outward to the terminals a progressive elevation of potential exists before the passage of a discharge. This brings into play the capacity of the secondary turns, as parts of a condenser receiving charge, and with high potentials this capacity is quite considerable. From the fact, as developed by my experiments, that such high potential apparatus needs to be carefully proportioned or otherwise the effects will be disappointingly small, I am satisfied that such relations should exist between the inductance and the capacity of the secondary conductor as to keep it in phase with the primary oscillations, and any condition which produces an undue positive or negative lag in the secondary phase will weaken materially the effects. It remains simply to state that of course the medium surrounding the apparatus is traversed by rather long Hertzian waves, which could readily be detected by proper resonators, and that further the apparatus can be used to charge the Hertz apparatus instead of an induction coil. I should anticipate that the production of the Hertz effects in a more continuous and vigorous way than hitherto would follow the adoption of these modern means for securing high potentials.

INFLUENCE OF THE INTRODUCTION OF A SULPHONIC GROUP UPON THE POWER OF A DEVELOPER.

By A. A. NOYES and W. K. GAYLORD.

Received April 24, 1893.

In making some experiments with para-amido phenol sulphonic acid, our attention was called to the fact that para-amido phenol is a photographic developer, and it seemed to us that it would be interesting to investigate the developing qualities of the sulphonic acid, especially as no accurate statements in regard to the influence of the sulphonic group upon developing power seem to have been made heretofore. The only mention we have found is that by A. and L. Lumière.[1] "Sulphonating does not appear entirely to destroy the developing power."

Preliminary experiments showed that para-amido phenol sulphonic acid is indeed a developer, and we have compared its action with that of the para-amido phenol itself. We exposed gelatine dry plates equal lengths of time under a negative in constant artificial light, and developed them partly with solution A and partly with B, which contain equivalent weights of para-amido phenol and its sulphonic acid as follows:

A. Para-amido phenol.		B. Para-amido phenol.	
Hydrochlorate	.05 g.	Sulphonic acid	0.7 g.
Sodium sulphite	8.0 g.	Sodium sulphate	8.0 g.
Sodium carbonate	2.2 g.	Sodium carbonate	2.2 g.
Water	100 cc.	Water	100 cc.

In one experiment the image appeared in solution A in 8 seconds, while in solution B 40 seconds were necessary. In the first case development was complete after 2 minutes; in the second only after $4\frac{1}{2}$

[1] Jahrbuch für Photographie, 6, 92.

minutes. From these figures it appears that the sulphonic acid is much less powerful in its developing action than the amido phenol itself. This result was confirmed by other experiments with plates exposed in the camera, the sulphonic acid taking always much more time for development than the amido phenol. Moreover the negatives so obtained are much weaker, and only by using much more concentrated solutions (*e.g.* 4 g. per 100 cc.) of the sulphonic acid and continuing development for a long time did we obtain fairly good negatives. Attempts to hasten the action by addition of more alkali resulted in negatives too weak.

From these experiments we conclude that the introduction of the sulphonic group has a greatly weakening influence upon the developing power of amido phenol. An investigation of other sulphonic acids in this direction would be of interest, since it is probable that the sulphonic group will be found to have a different effect according to its distance from the amido or from the phenol groups. A good example would be eikonogen (amido naphtol sulphonic acid) and the corresponding amido naphtol.

Massachusetts Institute of Technology,

January, 1893.

ELECTROLYTIC REDUCTION OF NITROBENZENE IN SULPHURIC ACID SOLUTION.

By ARTHUR A. NOYES and ARTHUR A. CLEMENT.

Received April 24, 1893.

When we undertook this investigation no successful experiments on the electrolytic reduction of nitrobenzene had been made. Within the last few months, however, several investigators have occupied themselves with this subject. Haeussermann[1] dissolved nitrobenzene in alcoholic soda, and in alcohol containing sulphuric acid, and obtained in the first case hydrazobenzene, and in the second, benzidine sulphate, as products of the reaction. By the electrolytic reduction of nitrobenzene-sulphonic acid in aqueous solution, however, he obtained m-sulphanilic acid. Elbs,[2] by interrupting the reduction before it was completed, obtained azoxybenzene and azobenzene in alcoholic soda. He found, remarkably enough, that anilin was formed by the reduction of nitrobenzene dissolved in alcohol acidified with sulphuric acid, when zinc was used for the cathode. Gattermann and Koppert[3] by using fairly strong sulphuric acid as the solvent obtained p-amido-phenol sulphate as the product. Our experiments were similar to theirs. We used, however, concentrated sulphuric acid, and obtained para-amido-phenol-sulphonic acid.

Our method was as follows: We dissolved 50 grams of nitrobenzene in 200 of concentrated sulphuric acid (1.84 spec. grav.), and placed in this solution a large platinum electrode and a porous cup containing strong sulphuric acid and a smaller platinum electrode. The outer vessel was surrounded with an asbestos mantle, and a current of about 3 amperes (potential 5 volts) was passed through the solution for 15 hours. The temperature remained between 80° and 90° C without application of external heat. The solution soon became deep blue, and remained so to the end. The sulphuric acid in

[1] Chemiker Zeitung 17, 129, 209.
[2] Idem, 17, 209.
[3] Idem, 17, 210.

the porous cell was partially drawn out by osmotic action; the remainder became gradually strongly fuming, owing to the decomposition of the SO_4 ion at the anode into SO_3 and oxygen and the solution of the former in the sulphuric acid. The specific gravity (at 20° C) rose in one experiment to 1.94. It is better, however, to dilute the acid in the porous cup from time to time, as otherwise the resistance becomes very great.

The product of the reduction is isolated by diluting the contents of the vessel with water and filtering. A greenish black mass remains on the filter. This is treated with a solution of caustic soda, and the residue of sulphur and carbon is filtered out and the filtrate neutralized with hydrochloric acid. A grayish or bluish white precipitate forms, which can be further purified by redissolving in alkali and reprecipitating with acid, or by crystallization out of hot water. This body proved to be a sulphonic acid almost insoluble in cold water, alcohol, and ether. It reduces silver nitrate solution in the cold with the production of a purple color; and the solutions of its salts turn brown rapidly in the air. It contains water of crystallization, which is entirely expelled at 100°, and decomposes at a high temperature without melting. An analysis showed it to be amido-phenol-sulphonic acid.

	Found.	Calculated for $C_6H_3(NH_2)(OH)(HSO_3)$.
C	38.11	38.09
H	3.87	3.70
N	7.06	7.41
SO_3H[1]	42.79	42.33

From its properties it is plainly the p-amido-phenol-o-sulphonic acid.

The yield from 50 grams of nitrobenzene amounted in three experiments to 30 grams of the anhydrous acid or 40 per cent. of the theoretical. Special experiments showed that the yield was smaller when two parts of sulphuric acid instead of four were used for one of nitrobenzine. The result was also less favorable at a lower temperature (50° – 60°). Above 100°, however, charring occurs.

Gattermann and Koppert diluted the sulphuric acid solution of the nitrobenzine with as much water as could be added without precipitating the nitrobenzene; and they obtained no sulphonic acid, but the

[1] Determined by titration with alkali.

sulphate of the para-amido-phenol. It is only possible to add about 4 grams. of water to 150 of sulphuric acid without causing precipitation, but this is sufficient to prevent entirely the formation of the sulphonic acid, as we confirmed by experiment.

It is worthy of note that Brunner and Kraemer[1] have also obtained p-amido-phenol-sulphonic acid by heating nitrobenzene with resorcin and concentrated sulphuric acid. In this case the resorcin evidently played the part of the reducing agent.

We have also studied the ease with which the sulphonic group can be broken off. This takes place quantitatively when the acid is heated to 170° in closed tubes with concentrated hydrochloric acid. The temperature at which the decomposition sensibly begins was determined by Mr. L. S. James to be 150° – 155°. The amido-phenol-hydrochlorate separates out in fine large white crystals on cooling, as it is only slightly soluble in concentrated hydrochloric acid.

We are now investigating the reduction product of dinitrobenzene.

April, 1893.

[1] Berichte der deutschen chemischen Gesellschaft, 17, 1867.

REMARKS ON THE DEDICATION OF THE NEW SCIENCE AND ENGINEERING BUILDINGS OF M^cGILL UNIVERSITY, MONTREAL.[1]

By FRANCIS A. WALKER, LL.D.

I PRESENT the heartiest congratulations of the Massachusetts Institute of Technology to the officers and teachers of McGill University, and especially to Dr. Bovey, on the fortunate completion and the present auspicious dedication to their destined uses, of these commodious and superbly equipped laboratories of physics and engineering. The distinguished position which this university has long held in science and the applications of science to useful arts cannot fail to be greatly advanced as the result of these noble benefactions of Mr. McDonald.

The growth of scientific and technical schools on this continent during the past thirty years has savored of the marvelous. In part, it has been due to the changed ideas and the transfigured ideals of the American People; in part, to the recognized need of greater skill and more of scientific knowledge for the development of the natural resources of the continent and for the direction of its growing enterprises. In this movement of the age, even the older institutions have been compelled profoundly to modify their traditional courses of study, substituting scientific and even technical instruction for much that was formerly deemed essential to a liberal education.

Of the reluctance, and even resistance which this movement has encountered from many who deservedly held high places in the old educational order, I would not speak with harshness. The notion that scientific work was something essentially less fine and high and noble than the pursuit of rhetoric and philosophy, Latin and Greek, was deeply seated in the minds of the leading educators of America a generation ago. And it has not even yet wholly yielded to the demonstration offered by the admirable effects of the new education in training up young men to be as modest and earnest, as sincere, manly, and

[1] February 24, 1893.

pure, as broad and appreciative, as were the best products of the classical culture, and withal, more exact and resolute and strong. We can hardly hope to see that inveterate prepossession altogether disappear from the minds of those who have entertained it. Probably these good men will have to be buried with more or less of their prejudices still wrapped about them; but from the new generation scientific and technical studies will encounter no such obstruction, will suffer no such disparagement.

Another objection which the new education has encountered is entitled to far more of consideration. This has arisen from the sincere conviction of many distinguished and earnest educators that the pursuit of science, especially where its technical applications are brought strongly out, loses much of that disinterestedness which they claim, and rightly claim, is of the very essence of education. For the spirit of this objection I entertain profound respect. I only differ from these honorable gentlemen in believing that the contemplated uses of science, whether in advancing the condition of mankind or even in promoting the ulterior usefulness, success, and pecuniary profit of the student of a technical profession, do not necessarily impair that disinterestedness which I fully concede is essential to the highest and truest education of the man. These gentlemen appear to me to have an altogether unnecessary fear of the usefulness of science. They entertain much of that dread of "Fruit," which Macaulay, in his famous essay on Bacon, doubtless with something of exaggeration, as his custom was, attributed to the old philosophers.

I am willing to admit that, in my humble judgment, many technical schools have erred in addressing themselves too closely to the practical side of instruction; that they have in some degree neglected principles in the study of science, and have borne an undue weight upon mere knacks and labor-saving devices and technical methods. I believe that in doing this they have made a mistake, even from their own point of view, and with reference to the very objects they profess. Moreover, I am free to acknowledge that those who direct many technical schools have made a mistake, in altogether, or nearly so, omitting from their curriculum philosophical as distinguished from scientific, liberal as distinguished from exact, studies. Those technical schools will best accomplish their purposes of usefulness, alike to their students and to the State, which make more of the sciences than of the arts, more of principles than of their applications, and which offer to

their pupils, in addition to the studies which will make them exact and strong, some of the studies and exercises which will help to render them, at the same time, broad and fine.

With only such a subordination of technical and scientific studies as is for the ultimate advantage of the technical professions themselves, and with such a complementing of scientific by philosophical studies as has been indicated, I believe that the work of the student in schools of technology is as fully entitled to be termed disinterested as that of a student in a classical college. In neither class of institutions can or ought the student to be unmindful that his personal success in life and his professional and social position are largely to depend upon the manner in which his work shall be done in college. All that can be asked in regard to any school is that there shall be zeal in study, delight in discovery, fidelity to the truth as it is discerned, high aims, and ambitions which have not sole or primary respect to material rewards. The strong desire to become a useful man, well equipped for life, capable of doing good work, respected and entitled to respect, constitutes no breach of disinterestedness, in any sense of that word in which an educator would be justified in using it with commendation.

The practical uselessness for any immediate purpose of a given subject of study may be no reason why it should not be pursued; but, on the other hand, the high immediate usefulness of a subject of study furnishes no ground from which the educator of loftiest aims and purest ideals should regard it with contempt or distrust. In either case, the question of real import is in what spirit the study is pursued. The most distinguished French writer of to-day on matters of education, writing, too, in advocacy not of physical but of social science, has frankly paid his tribute to the disinterestedness of spirit and loftiness of motive which promote and direct scientific research, even in its most practical applications. "Let us," he says, "pass in review the great founders of modern science and the creators of industry, the Keplers and the Fultons, and we shall be struck by the idealistic and even Utopian tendency peculiar to them. They are, in their own way, dreamers, artists, poets, controlled by experience."

And if, leaving abstract reasoning, we turn to contemplate the manner in which the several professions are practiced in the community, I seem to find corroboration of the view that the study of science and its applications to the arts of life do not tend to produce sordid

character or to confine the man merely to material aims. Every profession has its black sheep and its doubtful practitioners; but, while frankly admitting that there are mercenary physicists and chemists for revenue only, I boldly challenge comparison between the scientific men of America, as a body, and its literary men or even its artists, in the respects of devotion to truth, of simple confidence in the right, of delight in good work for good work's sake, of indisposition to coin name and fame into money, of unwillingness to use one thing that is well done as a means of passing off upon the public three or four things that are ill done. I know the scientific men of America well, and I entertain a profound conviction that in sincerity, simplicity, fidelity, and generosity of character, in nobility of aims and earnestness of effort, in everything which should be involved in the conception of disinterestedness, they are surpassed, if indeed they are approached, by no other body of men.

Let us, then, cheer on every enterprise for the extension of scientific and technical education, without any misgivings as to its effects upon the character and subsequent life of the young men of America, without any fear that they will be rendered sordid in spirit or low in their aims by reason of the practical usefulness of the studies to which they are called to apply themselves. There is a wonderful virtue in the exact sciences to make their students loyal, just-minded, clear-headed, and strong against temptation. Here, no insidious tendencies to mere plausibility, to sophistry, and to self-delusion beset the young and the ambitious. The only success here is to be right. The only failure possible is to be wrong. To be brilliant in error here is only to make the fact of error more conspicuous and more ludicrous. Nothing but the truth, nothing less than the whole truth, this is the dominating spirit of the laboratory, which never withdraws its control over the student to keep him from the false path, which never intermits its inspiration as it urges him onward to the light.

AN INVESTIGATION OF THE EXCURSION OF THE DIAPHRAGM OF A TELEPHONE RECEIVER.[1]

By CHARLES R. CROSS and ARTHUR N. MANSFIELD.

Received May 20, 1893.

In a paper by Messrs. C. R. Cross and H. E. Hayes[2] it was shown that with a magneto-telephone receiver the magnitude of the change in the strength of the magnet when a weak current is sent through the coil increases up to a certain limit as the strength of the magnet is increased, and then diminishes, the explanation of this diminution being found in the approach of the diaphragm toward saturation. The effect of varying the thickness of the diaphragm upon the magnitude of this change was also studied, and it was found that within the limits of the experiments the changed strength of the magnet due to the weak current is greater with thin than with thick diaphragms.

From these results it would naturally be inferred (1) that the amplitude of the vibration of the diaphragm of a telephone receiver would at first increase to a maximum, and then diminish, if the strength of the magnet were continually increased; and (2) that, within such range of thickness of diaphragm as would probably be most suitable in practice, a thin diaphragm is preferable to a thicker one.

The subject has also been studied by Mercadier,[3] by ascertaining the distance at which the beat of a metronome, when transmitted by telephone, just ceased to be audible under different conditions of the receiver as to the thickness of the diaphragm and strength of the polarizing magnet. In Mercadier's experiments the thickness of the diaphragms was varied through a far greater range than in those of Cross and Hayes, but their results are in substantial accordance with his for the same conditions of experiment, although the range of thickness

[1] Read at a meeting of the American Academy of Arts and Sciences, May 24, 1892.

[2] Technology Quarterly, **3**, 295.

[3] Comptes Rendus, 1889, **108**, 735, 797; 1891, **112**, 96.

in the diaphragms used by them was probably too small to produce the peculiar alternations of effect noticed by the former observer.

It seemed to the present writers desirable to verify these conclusions by direct observations upon the motion of the diaphragm itself, and the investigations detailed were undertaken with this end in view. We have thus far considered only the first of the two propositions just stated, leaving the second for future study. The experimental work was completed during the spring of 1891.

As it is very desirable not to have the free motion of the diaphragm interfered with in any way, we decided to make use of the stroboscopic method of observing its vibrations.

The telephone which we employed as a receiver had for its polarizing magnet a bar of Norway iron three fourths of an inch in diameter and eight inches long, which was surrounded by a magnetizing coil consisting of 2,750 turns of No. 18 (B. and S.) copper wire, whose resistance was approximately eight ohms. The line coil surrounding the end of the core was made of No. 36 (B. and S.) copper wire, and had a resistance of 99.5 ohms. The core was capable of being moved longitudinally by means of a screw, so that the distance of its end from the diaphragm could be adjusted. In all of our experiments the distance between the core and diaphragm was kept at $\frac{3}{64}$ of an inch. The strength of the magnet was varied by means of a resistance which altered the current passing through the magnetizing coil.

Since it seemed very doubtful whether the excursion of the diaphragm of the receiver when a current so feeble as that of a telephone was used would be sufficiently great to allow of satisfactory measurement, we decided to employ the alternating current from the secondary of a transformer through whose primary was passed the current from an ordinary alternating current dynamo making 128 complete alternations per second. By the introduction of a suitable wire resistance of variable amount into the secondary circuit the current flowing in it could be reduced to a convenient strength, so that when the magneto-telephone was placed in a derived circuit running from extreme points on this wire the coils were traversed by a current comparable in magnitude with the ordinary telephone current. By operating with a current thus produced, and passing through the coils of the receiver, we hoped to be able to employ a current somewhat, but not very greatly, larger than the ordinary telephone current, so that we might safely assume that the character of the phenomena observed with the former

under the different conditions considered would be substantially the same as those occurring with the latter and weaker current.

The alternating current thus produced, which we will call the "line current," was measured by an electro-dynamometer included in the circuit and placed between the resistance frame and the telephone coil. This electro-dynamometer was constructed especially for the purpose, and was calibrated in the ordinary manner by passing a direct current of known and variable strength through its coils, making the usual reversals to eliminate the effect of the earth's magnetism.

The intermittent illumination needed for the purposes of our experiment was furnished by the sparks produced by a Helmholtz tuning-fork interrupter, making 128 complete vibrations per second. At each vibration, when the style broke contact with the mercury in the cup, a bright spark was produced. The fork was so placed that this flash should illuminate the field of a microscope which was placed opposite, and focussed upon the end of a style carried by the diaphragm of the receiving telephone. The illumination given by the sparks, especially when concentrated by a lens, was abundantly sufficient to enable the observer to see the style as a silhouette against a bright field. The telephone was so placed that the vibration of the style was in a horizontal direction. When no current passed through the telephone the style was of course seen continuously, on account of the rapid recurrence of the sparks. If the rate of alternation of the alternating current employed is exactly 128 per second, thus coinciding in frequency with the sparks, then when this current is sent through the telephone coil, although the diaphragm will enter into corresponding vibration at the same rate, yet the style carried by it will still seem to be at rest when viewed by the microscope. But if the rates are not exactly the same, then of course the familiar stroboscopic effect will be produced, and the style will appear to be in a state of slow vibration, so that the amplitude of the vibration, if sufficient in amount, can readily be measured by means of a spider-line micrometer.

Using an objective having a focal length of half an inch, and an eye-piece of moderate power, and with a very weak magnet in the telephone, we found no difficulty in producing a perfectly measurable vibration with a current of only 5 milliamperes, while with a current of 29.5 milliamperes the excursion rose to fourteen thousandths of a millimeter.

On passing a current through the magnetizing coil alone the dia-

phragm is of course immediately drawn towards the core by a certain fixed amount depending upon the magnitude of the current. Some measurements were made which show the amount of this deflection with increasing values of the magnetizing current. The results of these are given in Table I. The current is given in milliamperes, the deflection in thousandths of a millimeter.

TABLE I.

Current.	Deflection.
14	0.0
46	1.7
85	6.7
123	16.7
155	29.2
195	45.9
246	80 8
300	130.1
367	200 0
431	272.8
473	297.0
502	330.0
604	335.0

We did not carry the increase of current to a higher value, since the deflection of the diaphragm would have become so great as to carry the style out of the field of view.

A comparison of these results — best seen by plotting them as a curve, which we have not thought it necessary to reproduce here — shows that on increasing the magnetizing current the corresponding permanent deflection increases more and more rapidly in proportion up to a value of about $\frac{3}{10}$ of an ampere, after which the deflection is very closely proportional to the current.

In studying the effect of different degrees of magnetization of the core of the receiver upon the amplitude of the vibration of the diaphragm, our mode of procedure was to pass a known direct current through the magnetizing coil, and to vary the alternating line current through the receiving telephone coil, measuring this current by the electro-dynamometer. The extent of the excursion of the diaphragm for each different current was measured by the spider-line micrometer. The deflections given in the tables are each the mean of five readings. The process described was followed for various values

of the magnetizing current, with the results shown in Table II. The figures in the first vertical column indicate the serial number of the measurements; those in the second, the strength of the magnetizing current in milliamperes, to which the strength of the magnet was found to be proportional; the figures in the upper line headed L, the various values of the alternating line current in milliamperes; and the figures in the columns vertically beneath these last, the corresponding amplitude of vibration of the diaphragm in thousandths of a millimeter.

TABLE II.

No.	M.	L.			
		5.0	12.5	21.0	29.5
1	77	4	7	10	14
2	123	8	14	21	27
3	180	12	23	34	43
4	235	17	28	39	47
5	287	23	47	63	81
6	322	37	76	102	127
7	352	44	86	106	130
8	376	31	71	100	120
9	394	26	68	88	113
10	416	30	60	87	107
11	459	22	40	56	69
12	503	16	30	39	50
13	564	8	17	28	36
14	639	8	12	16	21

The results of a portion of the measurements are shown graphically by the curves in Figure 1. Only series 1, 3, 5, 6, 7, 11, 13, 14, are reproduced, as a greater number would have been likely to render the diagram confused. The abscissas are excursions of the diaphragm in thousandths of a millimeter; the ordinates, the line currents in milliamperes. The several curves are numbered to correspond with the serial numbers in the table.

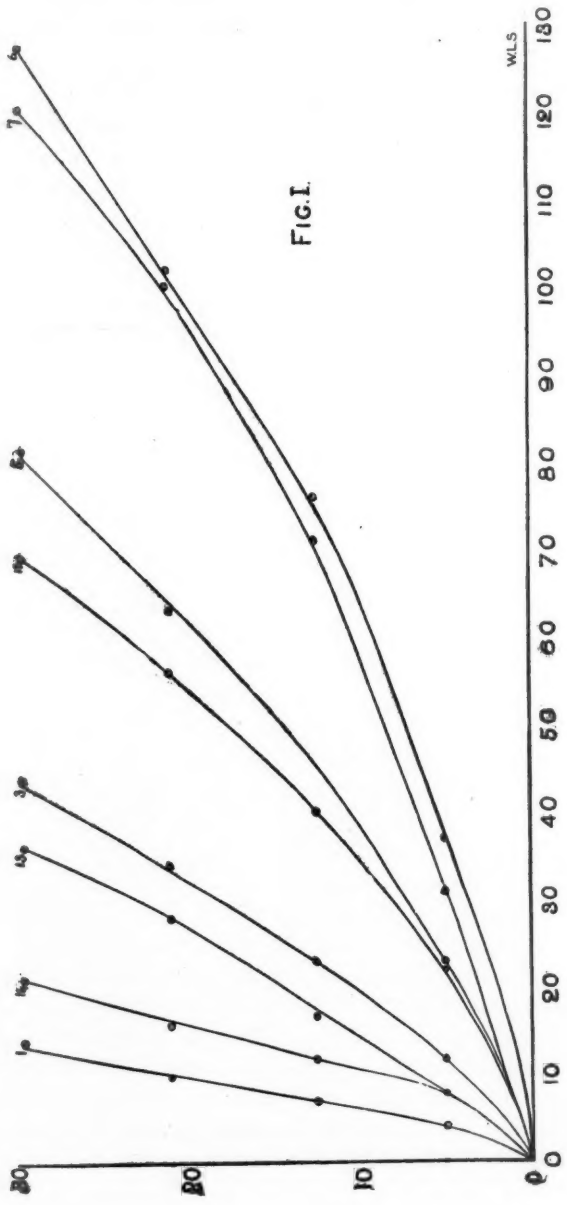

FIG. I.

It will be seen from these results that, as the strength of the magnet of the telephone increases, the amplitude of the vibration likewise increases up to a certain limit and then falls off. A comparison of them with a curve representing the magnetization of the magnet as determined by means of a ballistic galvanometer showed that the maximum motion of the diaphragm with a given value of the alternating line current is reached before the core reaches half saturation.

An inspection of the curves also makes it plain that in general the amplitude of vibration of the diaphragm increases less rapidly than the current actuating the telephone.

In the experiments previously described the strength of the magnet was kept constant in each series, and the line current was varied. A series of measurements was also made in which the strength of the line current was kept constant, while the strength of the magnetizing current was varied, which shows very clearly the manner in which the amplitude of vibration changes with change in the strength of the magnet. Table III gives the results obtained. The currents and amplitudes are given in terms of the same units as heretofore.

TABLE III.

Current.	Amplitude.
35	5.5
76	13.6
149	20.5
208	42.3
256	60.8
273	66.0
302	84.5
321	106.5
352	111.5
378	99.8
398	89.6
480	45.4
560	28.0
671	11.6
780	8.5
984	4.0
1,142	3.0

Beyond the highest value given in the table, 1,142 milliamperes, the excursion seemed to remain almost constant and of too small a magnitude to be measured readily.

Figure 2 illustrates graphically the results obtained. The amplitudes of vibration are represented by the ordinates of this curve, while the abscissas represent, in terms of an arbitrary unit, the strength of the field at the diaphragm, as obtained from the previously constructed curve of magnetization already referred to.

The figures obtained in these measurements lead to precisely the

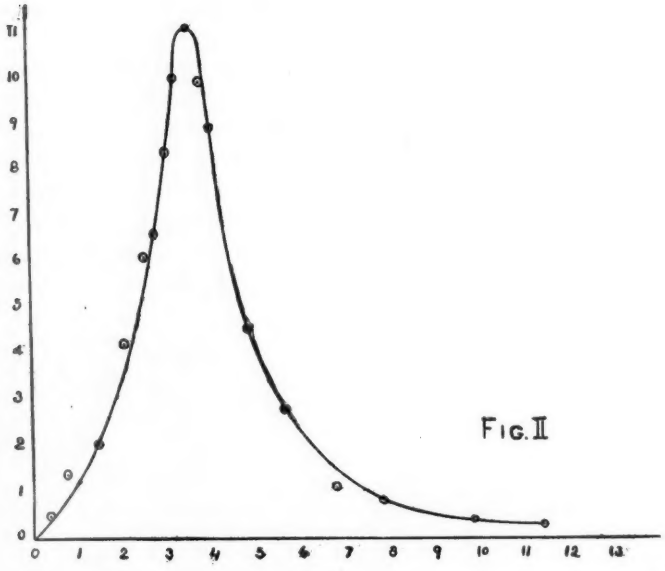

FIG. II

same conclusion as those already discussed, showing that the amplitude of the vibration of the diaphragm produced by an alternating line current of a given strength increases up to a certain point, and then decreases to a very low value. The point of maximum amplitude is far below the saturation limit of the magnet. It is evident, then, that it is not desirable to use an excessively strong magnet with a magneto-telephone receiver — a result which agrees with the conclusions set forth in both of the papers cited at the beginning of the present article.

Our observations were not made with the direct intention of deter-

mining the absolute magnitude of the excursion of the telephone diaphragm, but they may throw some light upon the subject regarding which the figures given by different observers differ widely. Dr. C. J. Blake,[1] by inscribing the vibration on a plate of smoked glass, obtained a value of 0.02 mm., and by the use of a micrometer screw with galvanic contact a value of 0.0135 mm. Salet[2] employed an optical method similar to that employed by Fizeau for measuring the expansion of solids, based upon the variation in position of Newton's rings when these were formed between a light piece of glass carried by the telephone disk and a fixed disk of the same material placed in front of it. The excursion as thus measured was from 0.0002 mm. to 0.0003 mm. Fröhlich[3] measured the excursion by means of a beam of light reflected from a mirror carried by the diaphragm, the beam being cast upon a screen and its motion measured when the receiver was operated. He gives 0.035 mm. as the value of the amplitude of the motion of the diaphragm. Franke[4] employed an optical method similar to that used by Salet, making the assumption that the amplitude of the vibration is proportional to the strength of the current — a supposition, however, which our own results, as given in the preceding pages, do not fully bear out; he concludes that the excursion of the diaphragm for a sound which is just audible is less than 1.2×10^{-6} mm.

Some of these differences are doubtless due to the different transmitters used. Blake employed a box magneto-transmitter, Salet a hand magneto, and Fröhlich a microphone. Also it is very possible that in some of the methods there is more or less interference with the free motion of the diaphragm. The following considerations may therefore be of interest, although they do not lead to absolutely conclusive results.

In all of our experiments the line current had a value considerably in excess of even a strong telephone current. The weakest value of the line current employed was five milliamperes, while even two milliamperes is a large value for a telephone current produced by a powerful Hunning microphone transmitter. Hence the actual values of the

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[1] Journal of the Society of Telegraph Engineers, 1878, **8**, 178.

[2] Comptes Rendus, 1882, **95**, 178.

[3] La Lumière Electrique, 1887, **25**, 180.

[4] Elektrotechnische Zeitschrift, 1890, **11**, 288.

excursions measured by us are much larger than those assumed by the diaphragm of the telephone receiver in practice. We have, however, endeavored to calculate this approximately from the data at hand. It is clear that, if we can obtain the equation of one of the curves in Figure 1, which corresponds to a strength of field of the magnitude employed in the ordinary telephone receiver, we may from this obtain the desired result by substituting in this equation the value of the telephone current. A study of the curves shows that they are all approximately parabolas with the equation $y^2 = mx^n$, n being greater than 2, but the values of m and n are different for the different curves. It was necessary, therefore, to determine by experiment the strength of the field actually employed in the magneto-receiver. This was done in the following manner. A magneto hand telephone was so placed that it produced a deflection of 45° in the needle of a delicate magnetometer. The telephone was then replaced by the magnet and magnetizing coil used in our experimental apparatus, and the current through the coil was varied until a deflection of 45° was produced in the needle. The current producing this effect was found to be 52 milliamperes. A like experiment being performed with a second telephone, the value of 62 milliamperes was obtained for the magnetizing current. The latter value was chosen as it came nearest to a strength of current which we had actually used, viz., 77 milliamperes, the lowest magnetizing current that we had employed.

By the use of the logarithmic method the equation of this curve was found to be $y^2 = 0.305\ x^{3.26}$, in which y represents the current and x the corresponding amplitude of vibration. Substituting in this equation the value of 2 milliamperes for y, this being the value of a strong telephone current, we obtain the corresponding value of x, which is 2.2; that is, the excursion of the diaphragm of a telephone receiver with the strength of field corresponding to the curve would be 22 ten-thousandths of a millimeter. But the true excursion is probably somewhat less than this, since the strength of field for which the equation holds is somewhat greater than that employed in the telephone, and for a magnetization of this value the deflection would be larger with the stronger field.

It may also be inferred from the preceding results, that so far as sensitiveness is concerned it would be advantageous to employ a stronger magnet in the receiver than is at present used. With the modern microphone transmitter this is not necessary, and upon lines

where there is much disturbance it would be harmful, as the proper procedure in such cases is to strengthen the transmitter as much as possible, in which case the receiver may be less sensitive. But if a less strong transmitter is used, as, for example, a magneto-telephone, and upon lines free from disturbance, increased sensitiveness in the receiver is very desirable.

ROGERS LABORATORY OF PHYSICS

May, 1892.

BACCALAUREATE SERMON.

By REV. E. WINCHESTER DONALD, D.D.

Trinity Church, Boston, May 28, 1893.

And King Solomon sent and fetched Hiram out of Tyre. He was a widow's son of the tribe of Naphtali, and his father was a man of Tyre, a worker in brass. And he was filled with wisdom and understanding and cunning to work all works in brass. And he came to King Solomon and wrought all his work. — *1 Kings vii: 13, 14.*

King Solomon is invariably represented as preëminently wise, and he never showed his wisdom more conspicuously than in his choice of a man technically skilled in the department of metal working to execute, and very likely to make, the plans of those parts of the Great Temple which required a union of strength and beauty. Hiram was selected because he knew how to do what he was asked to do, and for no other reason. He obtained his commission on his merits. His views of the sort of ritual the Temple Service was to illustrate, his opinions of the Ecclesiastical Canons which were to govern the official conduct of the priests, were not inquired into by the wise king. It was his competence to take charge of a most important branch of the splendid architectural undertaking which alone led Solomon to send down to Tyre a formal invitation to become chief engineer and architect of the famous structure. Like all too many men who have served their fellows faithfully and skillfully in the field of mechanical art, we know nothing of him save that he did his work well. Nothing better, however, could be known of any man.

The story is a picturesque and interesting illustration of the possibility of an intelligent and cordial union of the men of mechanical art with the men of institutional religion. Their real interests are one, and each is incomplete without the other. The Temple was no more Solomon's than Hiram's; Hiram's no more than Solomon's. Solomon furnished an idea; Hiram built a house for the idea. Which was the greater achievement let some one else debate and decide. At any rate, so exactly and splendidly did the great building express the superb idea of national unity and national worship, that when the idea became vague, became endangered by strife,

formalism, idolatry, and a spurious spirituality, there stood the great building lifting its huge bulk and glowing beauty against the sky, irrefragable testimony to the worth and blessing of loyal devotion to the God of righteousness, truth, and justice. Hiram's work saved Solomon's idea in more than one crisis of Israel's history.

But the cordial union of the men of mechanical art with the men of institutional religion in a visible, particular undertaking, is really an exhibition of the principle of essential interdependence which runs through all life to give it substance and unity. The claim of any science or of any profession to a rightful domination over every other is thoroughly irrational. A church regnant, or a university regnant, would mean inevitably disturbance and loss in the life of mankind or nation. Primacy in all things is safely placed in the hands of no man, nor in the custody of any body of men representing a single department of human activity, knowledge, skill, or purpose. Civilization is as safe in the hands of chemists as in the hands of priests, and no safer. Civilization is at its best when it is the outcome of the sympathetic, intelligent, reasoned union of all human forces. Distrust, depreciation, denunciation, from whatever quarter they come, are marks of a disturbance of the normal relations of one activity and its achievements to another activity and its achievements. The cry for the reconciliation of religion and science is a stupid cry, and has recently become irritating to our ears; but the wish for the cordial agreement and intelligent coöperation of religious men and scientific men is one of the most acute of our time, and one which there are reasons for believing may one day be realized. But it will be fulfilled, not by a similarity of methods, not by identity of pursuits, still less by successful attempts to subordinate religion to science or science to religion; it will be most finely and lastingly fulfilled by the universal recognition that the establishment of any fact and the verification of any truth, the discovery of any laws and the mastery of any force, are equally contributions to the discipline and development of human life, and are equally necessary to the final completion of human life upon our globe.

And I like to think that the circumstance which has brought us together this afternoon is indicative of the existence of a belief among you that what science stands for and what religion represents belong to one another. The work of Trinity Church and the

work of the Massachusetts Institute of Technology are not hostile or alien to one another, however variant be their methods and the material with which each has to do; rather are they allies rendering to man different but equally imperative services, and rightly expectant of man's gratitude and support because of the intrinsically valuable nature of the service rendered. You asked the use of this church and the voice of its minister because you wished, before going out into the untried future, to implore the blessing of God upon yourselves and upon the tasks which years of toil and training have fitted you to perform; and you are the more ready to ask for that blessing because of your deep, intelligent conviction that these tasks, and the skill you have patiently acquired for meeting them, may rightfully claim the help of God. The church joyously, proudly, hopefully receives you because it recognizes the incalculable value to the world of your special knowledge and ingenuity, hailing you as the latest addition to the ranks of those who are making the world a better place in which to live and work.

It is this joint act of ours which I wish to emphasize, for, unhappily, an impression is widely prevalent that there is an inherent antagonism between the men who study material forces and the men who study spiritual forces. But that impression is totally unwarranted, for, in the first place, the natures of the men who have thrown their force into the different fields of human enterprise are identical. They are moved by the same elemental conceptions of what it is to be a man and of what being a man involves. The supremacy of conscience, the absolutely imperative claims of truth, the call of purity and honor and compassion, and the awful mystery of life and death, press equally upon us all. They are the inexorable conditions under which all men do any sort of work, the common meeting ground on which every one of us must stand to receive his orders, to be shown his duties, and be girded with the strength without which each of us cannot but fail and finally fall.

It is simply turning the world upside down to suppose that there is any imaginable legitimate field of human activity from which the great primary, elemental imperatives of life can be driven. The strain upon the conscience is the same for electrician and poet; the behests of truth confront the chemist and the priest; and the sense of the sacredness of human life moves the bridge-builder and the judge; for, apart from anything a man may have set himself to

do — nay, rather, in everything a man shall undertake — there is forever and forever the abiding question of what the man himself becomes. It cannot be eliminated. His beliefs may change, his habits alter, his aims mount higher or sink lower; no matter; he is forced to pass judgment upon himself more frequently than upon what he achieves. Sooner or later the fact that he is a man is seen to be more important than the special occupation which has absorbed his personal force. "What are you, O man, who have given the strength of your clever brain and the endurance of your body to the discovery and mastery of material and force? What are you, O priest, who have moved for years through your round of services? who have thought of love and law, of sin and holiness, of repentance and faith all your days. What of yourselves, as you stand among your achievements and count up your gains and losses?" Scientist, poet, priest, or citizen — you know that you must tell yourself what you have become, what you have helped other men to be. Here in the beautiful presence of God's House does it not become instantly and lucidly clear that identity of natures, not diversity of pursuits, determines whether there can be any inherent antagonism between the men who stand for science and the men who stand for spiritual forces in the world? If there haunts the mind of any of you to-day the suspicion or the wonder whether, in the new life to which this week you go, there are circumstances or conditions inherent in your training and in the pursuits for which that training has fitted you, which must separate you from the life of God and free you from the duty of obeying His laws, put it away from you as both irrational and unworthy of the nature you proudly bear. Make personal this corporate act of worship, and let it stand henceforth forever in your memory as the moment when you acknowledged that whatever you should be called to do you were to do it as the servant of God.

But more than this must be said. In one most splendid feature of endeavor the work of the man of mechanical art illustrates the inexorable necessity of truth. It is his function to discover what *is;* to wrest from ignorance knowledge of the properties of matter; to explore the subtle play of forces; to separate, combine, apply, transmit, transmute, regulate, and master them to secure special results. It is an absolute condition of such work that the worker must be unremitting in his fidelity to what really is. Every appar-

ent gain must be subjected to a pitiless test. Guesswork is ruled out if it cannot be reduced to certainty. A perhaps may produce an explosion; a peradventure negative the most brilliant theoretical result. Everywhere the cry is for a demonstration supported by indubitable tests. As a consequence there grows up the stern conviction that nothing but truth can live; that no falsehood is for a moment safe in the presence of innumerable and pitilessly stern tests, which sit as incorruptible judges in the supreme court of fact. There are no finer pages in our history than those which tell the story of the great men of science who have hastened to publish their mistakes when larger knowledge has convinced them of their mistakenness, who have gladly abandoned the very theories which gave them their fame when, by their own discoveries, they have been the first to learn that those theories were untenable. Without waiting for detection they have confessed error. Beyond all the contributions which men of science have made to the comfort, the glory, the expansion of our civilization stands this: that they have taught the world that nothing lasts save truth; that no theory and no plan which is not the legitimate child of truth and fact can ever be a permanent addition to the possessions of mankind. Literally a false weight is an abomination to the scientific man. He hates with an intelligent and scornful hatred everything which is something other than it pretends to be, because he is safe only with what is what it can be verified to be. He knows that for him to put the unreal for the real, the flimsy for the strong, the false for the true, in any least process or product of his art, is to destroy his work and to discredit himself. It is as if one should surreptitiously slip a false scale upon the draughtsman's table or a light weight into the chemist's rack. But is there anything which should so firmly link the man of science to the man of religion as love of truth, however fine they make the distinction between truth and accuracy? Fundamentally they are the same. And it is love of the truth in one field of endeavor which fits a man to love it everywhere. Right here, then, is a chance for the men of science and the men of religion cordially to clasp hands, recognizing that each is in search of truth, each anxious to display the value and necessity of truth, each determined that nothing shall pass unquestioned, whether it be the strength of a beam of steel, the purity of an acid, or the moral quality of an act, each

eager that only what is rooted in fact shall claim man's acceptance. Surely it will be the most natural of all natural acts that each should find in the other's work the complement of his own. How grateful should the man of religion be to the man of science for every discovery made in nature when that discovery is amply verified, for all thoroughly ascertained knowledge of how the world came to be, for every disclosure of the laws by which a wise God governs his universe! How grateful, too, should be the man of science to the man of religion for every demonstration of the value of holiness, the power of worship, the dreadfulness of spiritual disobedience, and the realized, evident, measured power of prayer in the domain of the spirit! The distrust of our scientific Ephraim would disappear, and the depreciation of our religious Judah vanish away in this chivalrous and cordial appreciation of the essential kinship of each other's work.

For too long — far too long — have men ignored the existence of the bond that binds all lovers of the truth together. For too long have they been marshaled in hostile armies and embittered by unreasonable strife. Is it too much to hope that the coming years are to be made lustrous by a new perception of the spiritual kinship of all men who are searching for truth in any field where it may be found, of the absolute spiritual identity of all results which rest upon what man can verify to the intellect, the conscience, the soul, of the race?

And yet once more: there is an identity of purpose which keeps the man of science and the man of religion at their work. That purpose is the service of our fellows. Sooner or later the results of all true endeavor become the common possession of mankind. Men who never heard of Plato use the Grecian's arguments when they talk politics, and are moved by his ideas when they dream of a social heaven on earth. There is no conception of truth too lofty to be translated into the vernacular of the multitude. In the universities have been born nearly all the great movements of modern times, however difficult it be to track them back to their source. And no brilliant discovery has ever been made by astronomer, chemist, geologist, electrician, mineralogist, or engineer that has not finally been turned to account in the utilities or adornments of life, or does not hold the promise of it before our eyes. The generous support which the public gives to all its schools of technical

art is the public's testimony to its faith in their value as contributors to the public stock. Every man who is discovering *what is*, but has been concealed, is serving his fellows. Every man who is finding new uses for old material is adding to the common capital. Every man who is eliciting and applying force is increasing the general power.

To furnish humanity with new tools wherewith to work richer results; to remove every obstacle to the freest play of all man's powers; to lessen danger and wear and waste; to increase safety and health and skill; to give ignorance and weakness a chance; to make everything that is helpful and pleasant plentiful — that is the purpose of those who are imagining and executing the astonishing things which signalize our day. I will not believe, on any evidence thus far offered, that the motive of our modern energy in the realm of physical science is a sordid eagerness for gain or a vulgar craving for fame. The man who discovers a new use for common material or a new application of an already measured force should be the man who feels the thrill of happiness of him who can stop the throbbing of a nerve or clear the perplexity of a bewildered brain; and more often than much shallow and foolish talk would lead us to believe, he is that man. The comforts and conveniences of life which strip toil of its harshness and multiply our personal force may be the instruments of spiritual culture, as, indeed, thousands are ready to testify they have found them to be. It ought to be so clear that no one need miss it that the men who bridge the stream and plan the house, who mine the coal and forge the steel, who compel the electrical force to turn a wheel or to blaze in light or to weld iron bars, are the servants of the people, and are furnishing them with the conditions under which fullest vitality is possible. And what said Jesus to his friends when they were debating the question of superiority among themselves? Who is greatest in the kingdom of heaven? The man who serves. He who gives a cup of cold water only shall not lose his reward. But what of him who brings down from its home among the beautiful hills, before subtle poisons have mingled with its limpid streams, the crystal water into every home of the city with a baptism of cleanliness and health — shall he lose his reward? He truly served his fellows and takes his place in the ranks with all who have made the life of man richer, fuller, stronger, whether by science

or by religion. He has been obedient to the great law of service as truly as were Luther and Wesley, Hampden and Lincoln, Raphael and Beethoven, Shakespeare and Browning, Savonarola and Phillips Brooks. Just as truth unites by a real instead of an artificial bond all lovers of the truth, so does obedience to the law of service make brothers of those who serve, whatever be the sort of service given. And when, as is always possible, they who have set themselves in any field to the cultivation of any fruit for the refreshment and sustenance of their fellows shall see that in Jesus Christ what man should be, nay, what man may become, is the noblest vision of the perfect man, then each of us shall be most profoundly moved to give our service from a motive so high and pure and lasting that the Republic, Utopia, the Kingdom of Heaven — call it which you will — shall be established on this earth, prepared to receive the New Jerusalem, the city of God, which hangs in the heavens over us ready to descend when the earth and man are fitted for its coming.

Gentlemen of the senior class, you stand to-day on the summit of the privilege of your years of discipline and training. You look back with gratitude, tinged with regret, perhaps, for days when faithfulness slackened; with a quickened throb of the heart that close ties and happy friendships are no longer to be strengthened and fed by daily companionships. But you look far down into the future that is beckoning you with its glowing hands. It is all bright with expectation and illimitable hopefulness. It ought to be. No one who has been young and still keeps his sympathy with youth would have it otherwise. Pausing for one quiet moment here in the quiet church you have heard of the essential nature of the work you are going to do. We send you out as searchers for truth and servants of men, who in that search and service are, by obedience to the law and love of God, to become yourselves the splendid illustrations of the power of truth, the nobility of service. The world wants you for the same reason that it wants the ministers and lawyers and doctors who shall be graduated next month across the Charles. It is counting upon you. It has been waiting for and calling you. And now you are ready. May God's blessing ever be with you, keeping your love of truth pure, your service noble. Accept the terms which truth and service offer you, "then burn to the socket!"

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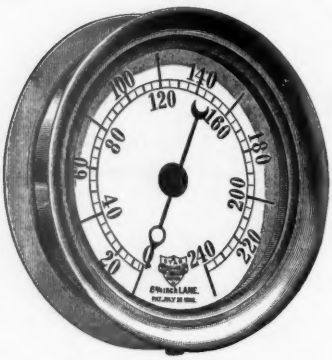

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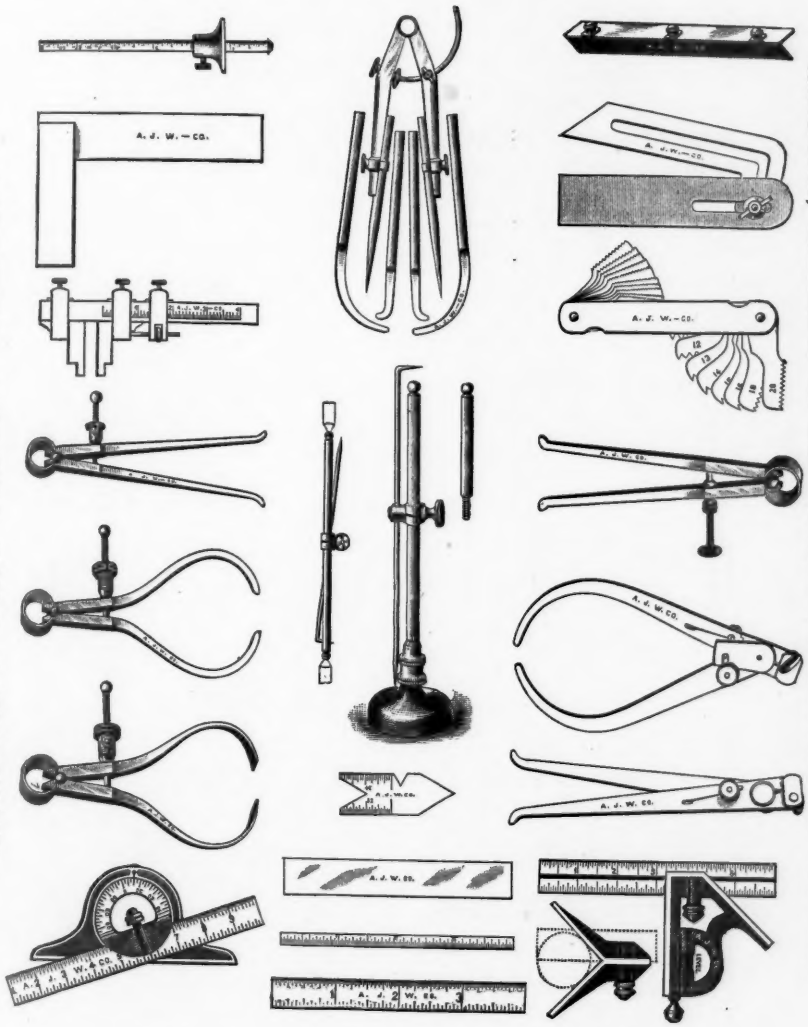

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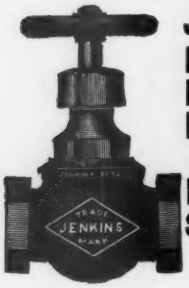

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